NATURAL HISTORY

5/91

AGE of DISCOVERY

IN SEARCH OF THE NEW WORLD

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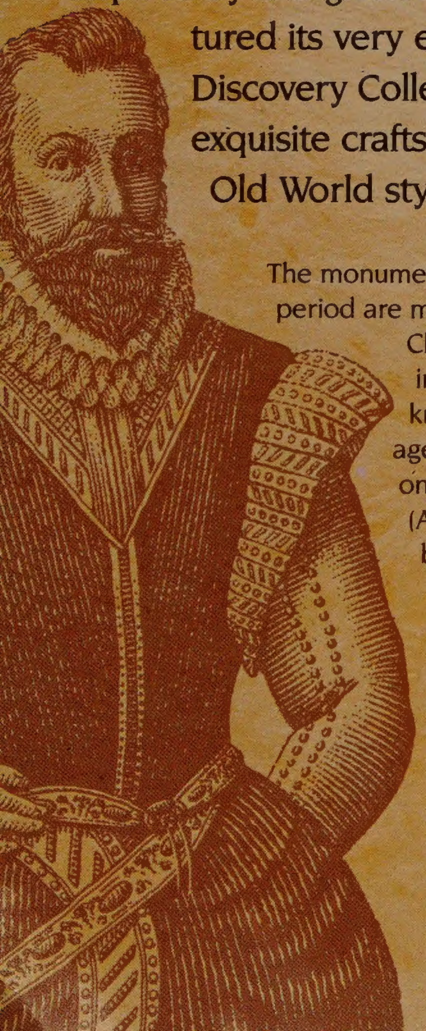
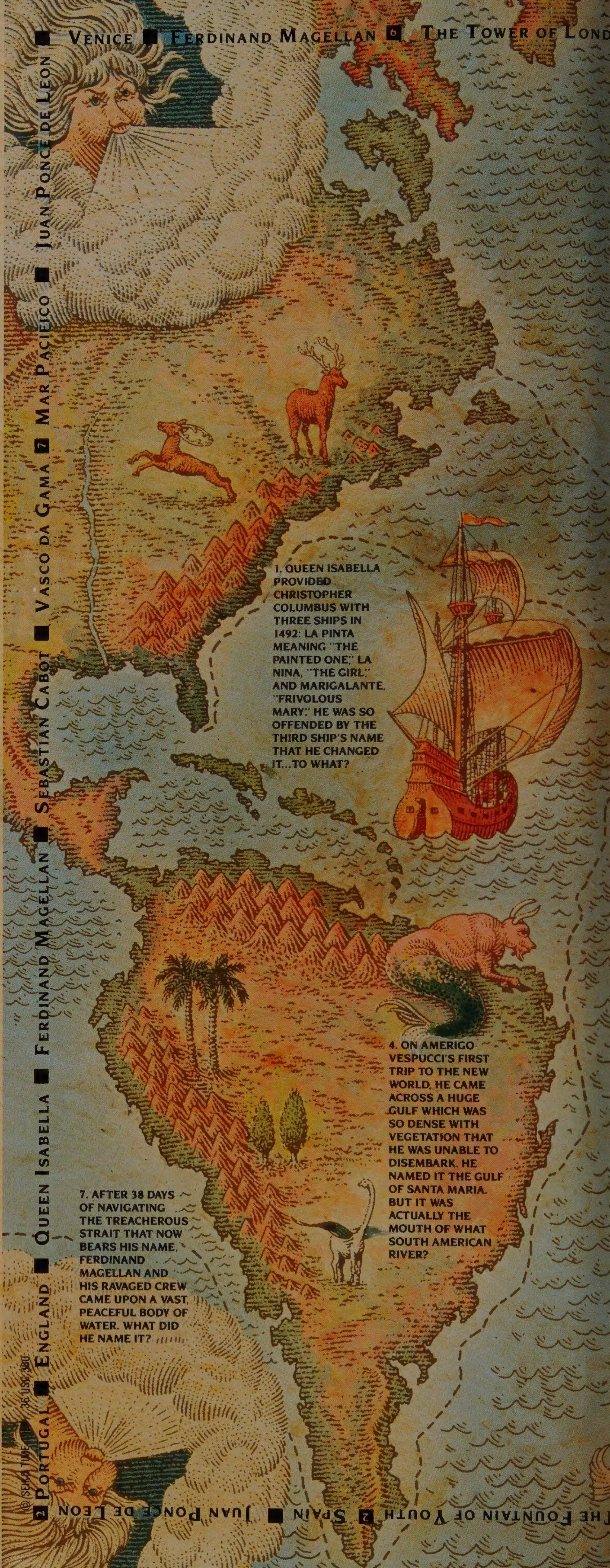


The monumental accomplishments of this period are more timely than a textbook. Challenge your memory, be inspired, and add to your knowledge of this triumphant age by answering the questions on these two pages. (Answers appear along the border of the map.)




CHRISTOPHER COLUMBUS ■ VENICE ■
SANTA MARIA ■ ITALY ■
VASCO DA GAMA ■ THE
6. AS QUEEN ELIZABETH'S MOST FAVORED COURTIER, SIR WALTER RALEIGH WAS CHOSEN TO OVERSEE THE ANNEXATION OF VIRGINIA. NOT LONG AFTER HER DEATH, HOWEVER, HE WAS IMPRISONED AND THEN EXECUTED AT WHAT NOTORIOUS LANDMARK?
5. THOUGH USUALLY ANGLICIZED, THE BEST CLUE TO THIS EXPLORER'S BIRTHPLACE IS HIS NAME: GIOVANNI CABOTO. BY WHAT NAME DO WE KNOW HIM AND WHERE WAS HE BORN?
2. THE AGE OF DISCOVERY WAS GALVANIZED BY A SEAFARING RIVALRY BETWEEN WHAT TWO IBERIAN COUNTRIES?
3. IN 1487, BARTOLOMEU DIAS USHERED IN THE AGE OF DISCOVERY WITH HIS VOYAGE TO THE SOUTHERNMOST TIP OF AFRICA. HE PROPOSED NAMING THIS DISCOVERY "THE CAPE OF STORMS," BUT KING JOAO II OF PORTUGAL INSISTED ON SOMETHING MORE VISIONARY THAN DESCRIPTIVE. WHAT DID HE CALL IT?
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QUARTZ
SEIKO
QUARTZ
World Timer
G·M·T
LOCAL T
SEC.
ALARM
AZORES
LONDON
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SANTA MARIA
KING MANUEL I ■ THE AMAZON RIVER ■
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NATURAL HISTORY

MAY 1991

COVER: *A* Physophora *jellyfish—a colonial animal buoyed by a gas-filled float—lives in the sea's thin upper layer, a worldwide habitat threatened by pollution. Story on page 58. Photograph by Norbert Wu.*

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58

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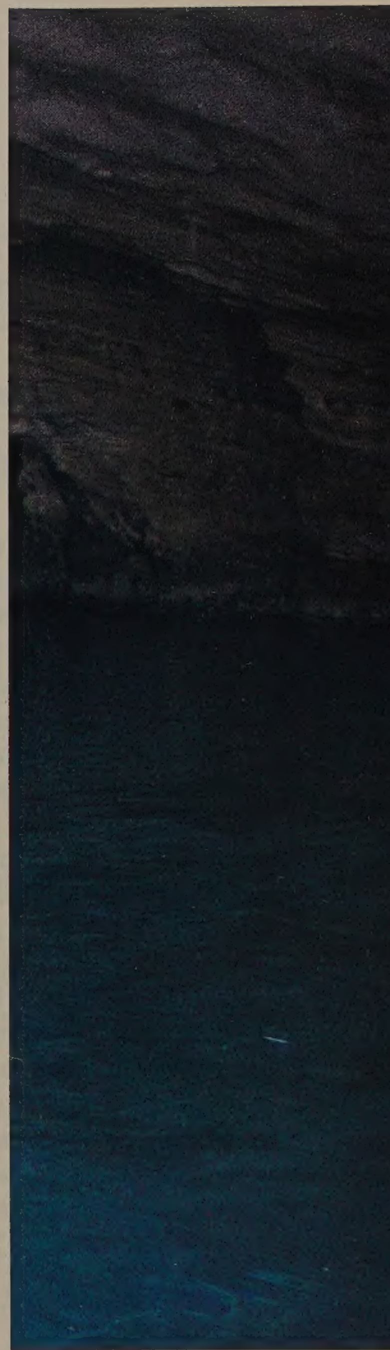
LIKE NARCISSUS, YOU'LL REFLECT ON THE CRYSTALLINE PURITY OF GREEK WATERS



NARCISSUS WAS AN ORDINARY MAN OF EXTRAORDINARY BEAUTY. SOME SAY, THE BEAUTY OF A GOD. HE DISCOVERED HIS BEAUTY REFLECTED IN CRYSTAL CLEAR WATER, SOMEWHERE IN GREECE. TOTALLY CAPTIVATED, HE NEVER LOOKED UP AGAIN.

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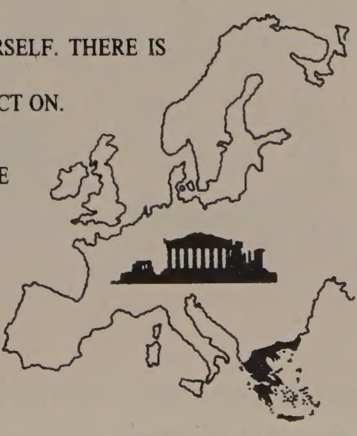

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The Road to Nakbe

A Maya urban center emerged in northern Guatemala 2,600 years ago

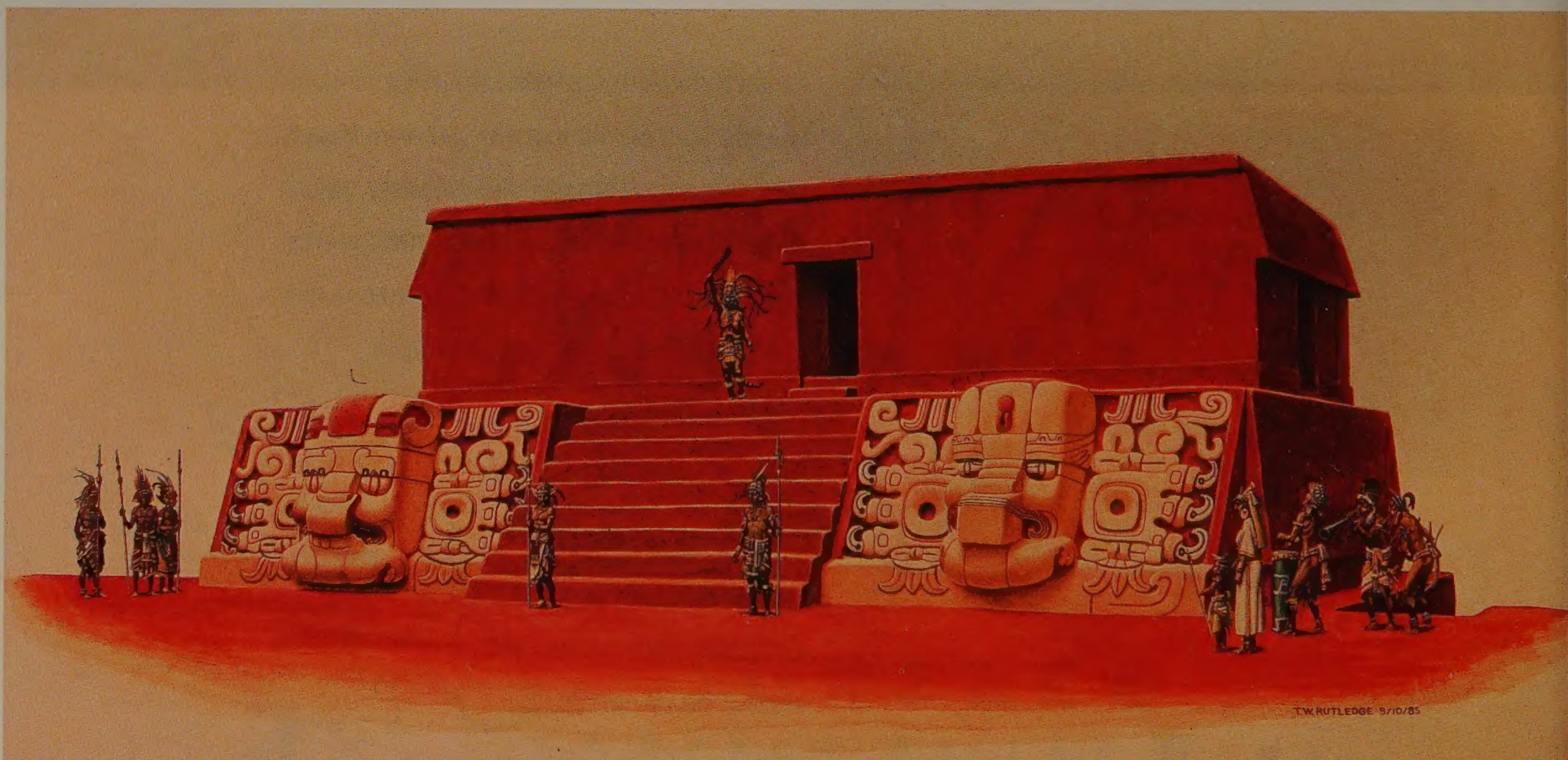
by Richard D. Hansen

I was apprehensive as I groped for yet another tree root entangled in the jumble of limestone blocks on the steep slope. Two days earlier, from the lofty pyramids of the archeological site of El Mirador, Guatemala, camp manager Bob Greenlee and I had taken compass bearings on our objective—the massive Structure 1 of Nakbe. Our expedition had then cut eight and a half miles across a formidable jungle *bajo,* or seasonal swamp, to the base of a large pyramidal mound. If, when we reached the summit, our compass did not read 314° degrees back to our starting point, then this would not be Nakbe, but some other, unknown site in the tropical forest, forcing us to continue our search through the never-ending canopy of green. As we emerged at the top, we felt a sudden sense of isolation; the momentary escape from the hot, humid, insect-infested forest was a refreshing pause. Our compass readings confirmed that we had reached our goal.

Nakbe was first reported in 1930 by an aerial expediticn from the University of Pennsylvania but was not visited by any scholars until archeologist Ian Graham located and mapped a portion of the site in 1962. Graham called it Nakbe, which means "by the road" in Yucatec Maya, a fitting name since a major ancient causeway can be observed extending across the *bajo* from El Mirador toward the site. My exploratory visit, in 1987, was to expand on my research at El Mirador, then the earliest-known Maya urban settlement. Two years later, in February 1989, a joint expedition sponsored by the Guatemalan Institute of Anthropology and History and the University of California at Los Angeles began systematic excavation and mapping of the site center, using 125 mules to transport supplies and equipment.

This is the fourth in a series of articles that explore recent findings and interpretations concerning the rise and fall of ancient Maya civilization.

The major architecture at Nakbe is divided into two principal clusters of platforms and mounds, one to the west and one to the east. The western group includes Structure 1, which at 150 feet is Nakbe's tallest pyramid, while the eastern group includes the 100-foot-high Structure 59, a massive platform surmounted by three mounds. To date, Nakbe has



Set atop a thirty-foot-high platform, stucco masks frame the upper stairway of El Mirador's Structure 34. The costumes shown in this artist's reconstruction are based on Preclassic Maya representations.

T. W. Rutledge

Joe LeMonnier

been probed by more than 150 major excavations, providing a fairly comprehensive sample of this core area.

The excavations include test pits to establish the stratigraphy down to bedrock, tunnels to determine sequences of building and rebuilding, horizontal excavations to reveal the façades of large public architecture and to expose small domestic structures, and narrow and wide trenches to fix the precise location and sequence of artifacts. We have also combed the haphazard trenches left by past looters, who visited the site in search of marketable artifacts. As a result of these excavations, we have located archeological remains dating from 3,000 to 1,000 years ago. The strongest evidence concerns the first 700 years, covering the middle Preclassic period and the beginning of the late Preclassic period.

For many years, the standard view of the Maya Preclassic was one of relatively primitive groups settling the tropical lowlands and gradually evolving into civilized chiefdoms. The era of Classic civilization, represented by the construction of large urban centers with massive architecture, writing, stone monuments, detailed art, and elaborate social and political hierarchies, was thought to have begun 1,700 years ago. In the past decade, however, work at sites such as El Mirador has revealed that the complexities of civilization actually extended back into the late Preclassic, the period from 2,300 to 1,700 years ago. Nakbe is now revising our views of the middle Preclassic, from 3,000 to 2,300 years ago, which at other lowland sites appears to be represented only by simple village remains.

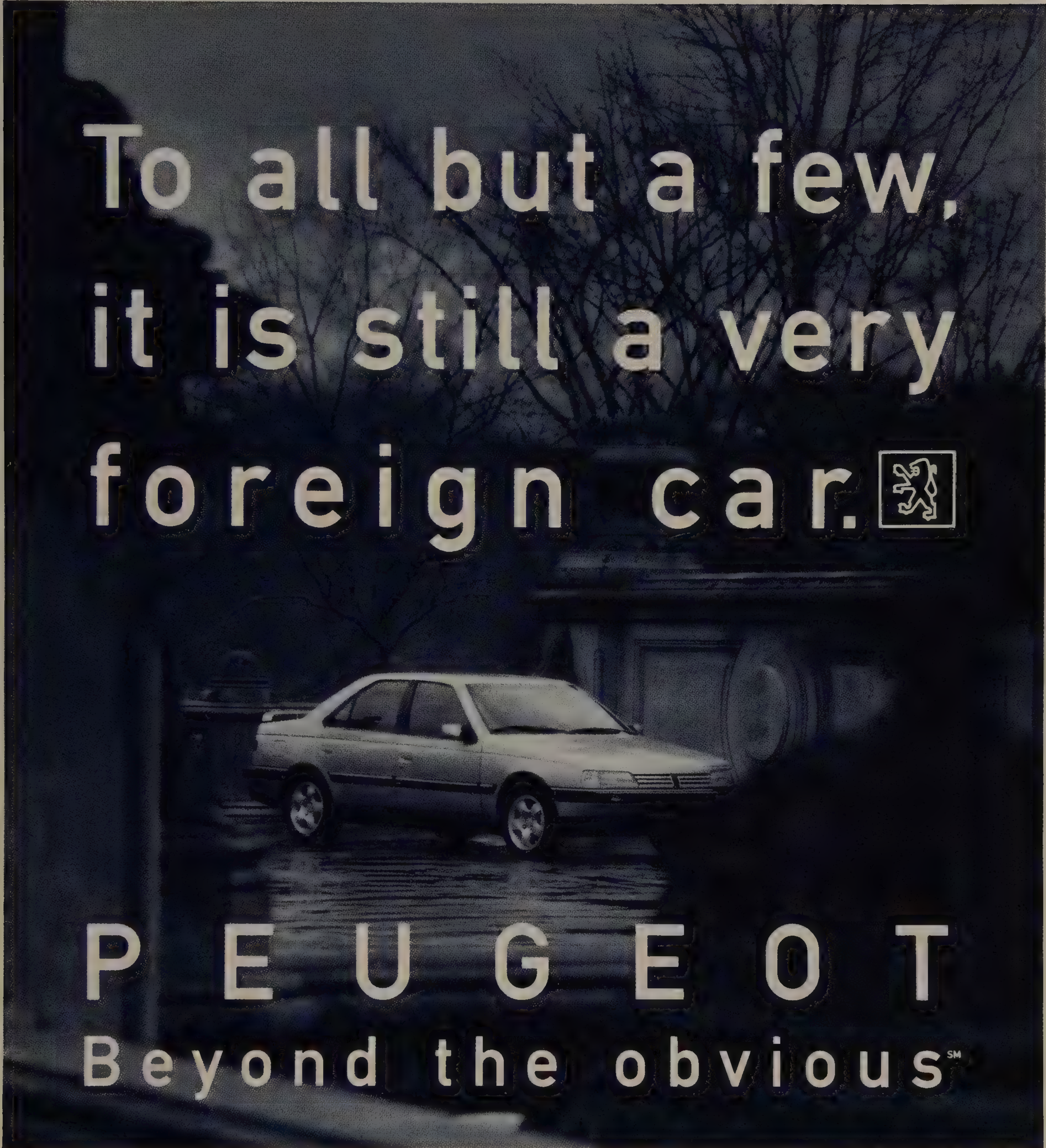
Based on numerous radiocarbon dates and ceramics from rich deposits throughout the site, we believe that the first inhabitants occupied Nakbe from 3,000 to 2,600 years ago. Why settlers chose this region in the first place has not yet been determined, but they appear to have quickly established a strong agricultural base. Preliminary studies at Texas A&M University by John G. Jones have identified abundant pollen from corn (zea maize) and squash in the early deposits.

The site center has yielded large quantities of middle Preclassic ceramics, currently being analyzed by Donald W. Forsyth of Brigham Young University. The pottery includes the red-on-cream, two-color bowls commonly associated with such deposits, as well as incised bowls, narrow-necked jars with coarsely painted bands, and a wide variety of one-color vessels—red, cream, or black—including *tecomates* (jars with narrow openings but without necks). We have also found numerous fragments of figurines depicting a wide variety of human and animal forms. Also common are shells through which holes were ground. Many were *Strombus* shells, a type of artifact unique to the first part of the middle Preclassic at Nakbe, Uaxactún, Tikal, and other sites where similarly dated deposits are located.

The shells reflect one of the earliest major imports into the interior of northern Guatemala, and I believe they and similar exotic imports, such as obsidian (a volcanic glass from which sharp tools could be fashioned), played an important role in the formation of an increasingly complex society. The demand for these materials, whether for cultural or economic reasons, and the mechanisms of procurement, transportation, and distribution that met that demand, required the development of administrative and governmental organizations at an earlier stage in this region than in areas where those commodities were more readily available.

Fairly direct evidence of developing differences in social and economic status includes human incisors with inlaid disks of jadelike stone, found in deposits dating to about 2,800 years ago. Such dental decorations are known to have been associated with elite status in later Maya periods. We have also found a middle Preclassic ceramic shard with a portion of an incised profile that displays the sloping forehead characteristic of later Maya elite society. This was a frontal cranial deformation that resulted from binding the head in infancy.

The earliest architecture known at Nakbe consists of low walls of carved limestone blocks, two to four courses high. These walls are associated with rich mid-



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dens and with a large limestone slab apparently used as an altar for community rituals.

Sometime between 2,600 and 2,400 years ago, a massive construction effort was carried out at Nakbe. Tons of rock were quarried and used as fill for platforms and pyramidal structures ranging from three to sixty-five feet high. These constructions established the precincts of much of the eastern and western architectural groups, burying the earlier structures and middens. The construction resembles that of less ancient structures in the Maya lowlands, with one important difference: we have detected no art on the façades. Such art seems to have appeared later, representing an innovation in architectural design and ritual emphasis.

For example, at least six large stucco panels and grotesque masks covered the upper façades in the final versions of Nakbe's Structure 1 and eighty-foot-high Structure 27, which were enlarged and remodeled about 2,300 years ago, at the beginning of the late Preclassic period. The panels depict large earspools (circular jade ornaments placed in the earlobes), droplet shapes most often found on the chin or forehead of masks, and trefoils (tridentlike appendages). The masks depict monsters with an exaggerated upper lip or snoutlike projection. In the case of Structure 27, large scrolls extended down and away from the open mouth of one mask we uncovered. These panels and masks may be the earliest yet found in the lowlands, a conclusion based on associated ceramics and the fact that the underlying limestone was laboriously carved prior to the application of stucco. At other sites, only the stucco was modeled to form the images, an apparent shortcut.

As in other examples in this region, the panels and masks at Nakbe flank the upper stairway of a characteristic design known as a triadic structure. This is a pyramidal platform with three small buildings on top arranged around a central stairway. Two of the buildings are placed on opposite sides, facing each other, and a third, larger one, in between and set back. At Nakbe, the masks and panels flank a stairway that had thirteen steps, which probably represented the thirteen levels of the Maya heavens. The architectural art suggests the early crystallization of religious beliefs that pervaded nearly a millennium of later Maya culture.

In the region of northern Guatemala where El Mirador, Nakbe, and similar sites are located, labor was mobilized for construction (usually of triadic structures) on a size and scale unparalleled at any other time in the entire Maya area. Con-

Richard D. Hansen

Posts brace the projecting upper lip of a mask on Nakbe's Structure 27.

sisting of more than 380,000 cubic yards of mud and stone, the Tigre pyramid at El Mirador, for example, is larger than the combined mass of Classic Tikal's Temple 1, Temple 2, Great Plaza, and entire North Acropolis. Perhaps the major means by which the ruling elite achieved this great social control was by manipulating a sophisticated religious ideology. The masks and panels that ornament the triadic structures are related to mythological deities, whose identities can be determined from later hieroglyphic texts. They do not refer to rulers or other historical figures, such as those commonly depicted on Classic carved stelae.

Major public architecture at Nakbe may have also served a practical purpose as a water-collecting facility. Northern Guatemala typically has about four months of dry season, from January through April, when water must be conserved and rationed. At present we have no water source at the site and are forced to supply our camp by transporting water on muleback from three and a half miles away. We have discovered what may be drainage systems that channeled water from several structures to serve the middle Preclassic inhabitants. Overcoming the lack of a local water source, as well as other specific environmental obstacles, to meet the needs of an expanding population may have been an additional element demanding the formation of effective government in the region.

One of the most unusual discoveries at Nakbe emerged from excavations around a small mound in the site's eastern group of architecture. We found forty-five fragments of an eleven-foot-high limestone monument, Nakbe Stela 1, which had been smashed in antiquity. When pieced together, the jigsaw puzzle revealed a carved scene, apparently duplicated on both sides of the monument, depicting two individuals who stand face to face and are dressed in regal costumes of a very early style. One of the two is pointing upward with an index finger to a disembodied profile head, which in turn is faintly joined to the headdress of the other.

Richard and Jody Hansen

A drawing reconstructs the details of Nakbe Stela 1, a limestone monument that was found in fragments. The 2,400-year-old stela may depict supernatural twins described in later Maya texts.

I am convinced that the scene is a representation of a myth that we know of from the Popol Vuh, a Quiche Maya text transcribed by a Dominican friar in about 1702. Possibly what is commemorated here is a ritual enactment of that myth by actual, historical personages. In any case, the two figures appear to portray the supernatural twins Hunahpu and Xbalanque, who were conceived when their mother was spit upon by the severed head of their father, Hun Hunahpu. Their father and his brother had been sacrificed after losing a ball game to the evil lords of the Underworld, and the twins ultimately avenged their father's death.

On Nakbe Stela 1, the figure that I identify as Xbalanque is pointing toward his father's severed head, apparently indicating the source of his divine lineage. The connection between the head and the headdress of the other twin, Hunahpu, is proper since he assumed his father's name. While using the accounts of a colonial text such as the Popol Vuh to reconstruct past mythological beliefs is highly speculative, the detailed iconographic clues found in the headdresses and regal costumes support this interpretation.

The form and style of this stela are definitely Preclassic, but the dating is difficult since the monument was installed on a small late Classic platform about 1,300 years ago (and sometime afterward, it was deliberately smashed). But an altar stone located immediately to the east of Stela 1 was sealed below a floor that dates to the latter part of the middle Preclassic. If Stela 1 was associated with that altar (in typical Maya fashion), then the sculpture probably dates to about 2,400 years ago. Further excavations around the altar are expected to clarify this issue.

The extreme antiquity of Nakbe and other sites, such as Guiro, El Mirador, and Tintal in northern Guatemala, allows a glimpse of a poorly known period in the early formation of complex Maya society. At El Mirador and Guiro, for example, we have recently discovered some of the earliest hieroglyphic texts in the Maya lowlands. These texts, possibly 1,950 to 2,050 years old, have yet to be deciphered. In addition, we have discovered a pattern in the placement of the Preclassic royal tombs that were looted at Guiro and Tintal. With this knowledge, we hope to uncover unlooted tombs in Nakbe and El Mirador.

While we have found at least some remains from nearly every period of Maya society at Nakbe, the site was never a major center after the beginning of the late Preclassic period. I had initially hoped to find remains of occupation from about 2,300 to 1,850 years ago, to further understand the nearby late Preclassic center of El Mirador. The last construction phases of the largest pyramids at Nakbe date to the beginning of this period, and the two sites were even joined by a causeway. But late Preclassic artifacts have proved sparse throughout the site of Nakbe, perhaps because the settlement was rapidly eclipsed by the rise of El Mirador. Nakbe remained virtually abandoned for a thousand years, until some late Classic Maya reoccupied the site. These people established small communities in and around the ruins and left some fine examples of Classic ceramics, but they built no monuments of their own.

I believe the spectacular rise of El Mirador was related to that site's better supply of water and especially to its more defensible position. The important public architecture at El Mirador was constructed on the brink of a steep escarpment, which provided protection to the settlement's northern and western flanks, while the eastern and southern sides were protected by a major wall. As the city's wealth and power increased, a suitable defense was apparently required to discourage competing polities from aggression. With the addition of this increased militarization, the society of the late Preclassic period in the lowlands of northern Guatemala had assumed nearly all the recognized features of Classic Maya civilization. □

Abolish the Recent

According to the geological clock, we are still in the throes of the Ice Age

by Stephen Jay Gould

Although Mark Twain quipped that familiarity breeds children, our clichés still identify "contempt" as the more common product of continuous presence. I confess that I cringe whenever Vivaldi's *Four Seasons,* not to mention Pachelbel's canon, wafts on the Muzak of a restaurant, an elevator, or in that most damnable context of all, the holding pattern of a phone call to almost any commercial establishment.

Too bad, for these are fine pieces of music, not intrinsically ripe for such mistreatment. Above all, we must remind ourselves that clichés usually attain their unwelcome status because they are true—and often profound—and debasement by simplified repetition is a consequence of value. This essay is rooted in a concept of importance, often compromised by a cliché. My theme is the invisibility of larger contexts caused by too much focus upon single items, otherwise known as missing the forest for the trees.

This phenomenon has two major sources. The forest may remain unperceived for the paradoxical reason that ordinary and perpetual presence easily becomes invisible. (The standard literary example, itself a cliché on the *Four Seasons* model, quotes Molière's *Bourgeois Gentilhomme:* "Good heavens! For more than forty years I have been speaking prose without knowing it.") But in a second reason, the subject of this essay and a vital theme in my profession of geology, contexts are invisible because they operate on a time scale too divorced from our immediate perception, although the context may control our lives. The *Book of Common Prayer* tells us, and who can deny it: "In the midst of life we are in death." But who can bear this in mind—and why should we—during the simple pleasure of a meal (minus Vivaldi on the Muzak)?

The Ice Age—the easily forgotten context discussed in this essay—has recently become all the more invisible now that legitimate fears of global warming have shifted immediate attention to melting icecaps and drowning cities. While we worry about advancing heat, the abstract knowledge of recent cold seems less and less relevant.

But the glacial epoch is not a completed episode of our geological past. We are in an ice age *now,* and our entire history (at least as the genus *Homo*) has unfolded under its influence. The first continental ice sheets began to form some 3.5 million years ago, and they have waxed and waned ever since. (Contrary to older views, the ice sheets did not come and go in four discrete pulses, but have cycled many more times, beginning imperceptibly with small and limited glacial growth and culminating in larger advances that, in North America, covered most of Canada and reached as far south as New York City. As a student at Jamaica High School in Queens, I used to cuss out the glacier every day, as I trudged up the hill formed by its terminal moraine, from a bus stop on the appropriately named Hillside Avenue to my school on the summit.)

The last ice sheet didn't begin its major phase of melting until a mere 11,000 years ago. We are now in a so-called interglacial period—presumably an interlude until the next readvance of the ice. In other words, the Ice Age didn't end with the last retreat of glaciers. It continues still—as it has for the past few million years—as periods of glacial growth alternating with melting. We happen to live in a transitory time of glacial retreat, but just as we progress toward death in the midst of life, we are still in a glacial age during the interregnum between continental ice sheets. An ice age is the entire regime of advance and retreat, not just the moments of maximal glacial growth.

Nothing about the *natural* history of climate gives us the slightest reason to think that this earthly style of the past few million years has ended and that the ice will not advance again. (This claim may, of course, be canceled if the unnatural history of human machination brings the cyclicity to a halt via a greenhouse effect or some other genre of anthropogenic warming. But then, other scenarios, including nuclear winter, might send our primary influence in the other direction.)

Popular culture is notoriously poor at understanding the geological view of time. In fact, we have trouble grasping anything that needs to be measured on a scale greatly different from the length of our lives. We can just about manage 1776; 1066 begins to get very dim, and more than a few thousand years eludes our comprehension. When we must think of a process cycling at frequencies measured in tens to hundreds of thousands of years (as with glacial episodes of our current ice age), we fail to grasp the amplitude and fall back upon our usual parochialism of viewing the present moment as an ulti-

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mate reality. Thus, since continental glaciers are not now extensive (unless you are a penguin in Antarctica or a Dane or Eskimo in Thule), and since grandma didn't witness them either when she was a girl, the Ice Age must be over.

I can forgive pop culture its foibles on the difficult issue of time scales, but professional geologists should not succumb to the bias of granting special status to the present moment. And yet our official alphabet, the geological time scale, enshrines this prejudice as a recognized category! The Cenozoic era ("age of mammals," according to another bias), the 65 million years since the mass extinction of dinosaurs and half the families of marine organisms, is divided into two periods called Tertiary and Quaternary. (These names, meaning "third" and "fourth," are remnants of an older version of the time scale. Before we learned enough to make finer resolutions, the billions of pre-Cenozoic years were roughly divided into "primary" [for oldest rocks without evidence of past life] and "secondary" [for fossil-bearing sediments].)

The Quaternary period, appropriately beginning with the onset of glaciation, is itself subdivided into two epochs, called Pleistocene and Recent. The Pleistocene is the time of ice ages, but what then is the Recent? (Please note the cachet of a capital R. The word is vernacular English, but the upper case designates an official term of approved jargon.) In a shameful bow to presentist prejudice, we define the Recent as the period following the last retreat of the glaciers—the vernacular misconception of "time since the end of the ice age." But no previous interglacial phase receives its own name, and our present version is unremarkable among these times of retreat. (The current interglacial does not mark the largest melting of ice and the greatest consequent rise of sea level. Our earth still maintains substantial accumulations of continental ice on Antarctica and Greenland. The last major interglacial, peaking some 120,000 years ago, yielded seas well above present levels.) The Recent, in other words, is a conceptual fiction constructed to assuage our desire for a distinctive present—a time of emergence from the gloom of past cold into the more hopeful light (and warmth) of a modernity defined by our domination. No such thing; we are simply living through an unremarkable interglacial phase in a continuing climatic regime of alternating glaciation and retreat. If the term Pleistocene has any geological meaning, we are still in it.

On a muggy July day in Washington, D.C., we may be forgiven for doubting that our planetary home remains in its Pleistocene regime. But an appropriate geological view should erase our skepticism for two reasons of appropriate amplitude. First, as argued above, the Pleistocene ice age features continental glaciers that wax and wane. The ice age is the entire process, not just the discontinuous times of maximal glacial advance. We are in a waning phase, and the ice will come again. Second, the entire earth, even at its current interglacial maximum, is an inclement place compared with more common climates during our 550-million-year history of multicellular life.

This is not an essay on the causes of ice ages—entire books and courses are devoted to this complex subject. Let me just say in passing that two separate issues must be addressed: (1) a cause of cyclicity; and (2) a general trend toward sufficient global cold so that the bottom of the cycle provokes growth of continental glaciers. Most geologists now favor periodic changes in the earth's orbit as the basic cause of cyclicity. These changes are a complex amalgam of variation in the earth's axial tilt, the eccentricity of its orbit about the sun, and precession of the axis (or change in its direction of pointing). For example, the Northern Hemisphere will have a particularly severe winter when axial tilt is high, the orbit is maximally eccentric, and precession produces our winter (maximal pointing of the North Pole away from the sun) when the earth is farthest from the sun. But these orbital cycles occur all the time, so why are ice ages not perpetual? We now must call upon the second factor, the general state of the earth's refrigeration. During most of the past 600 million years, the earth has been sufficiently warm so that even the bottom of an orbital cycle produced no icecaps. But the past 65 million years have witnessed a slow and general decrease in global temperatures—for complex reasons, involving dispersal of continents, growth of mountain ranges, and movement of the poles out of open oceans (which do not freeze) onto continents (Antarctica) and largely isolated shallow seas (the so-called Arctic Ocean) that can easily become ice covered. In short, the earth is now generally cold enough to "kick in" a glacial phase at the bottom of an orbital cycle.

Thus, whatever our stage in the orbital cycle, we are living on an unusual earth in an extraordinary geological time. Our planet is now colder, more sharply divided into climatic belts by latitude, and far more restricted in its tropical regions than in most past times. Dinosaurs once ranged as far north as Spitsbergen, and extensive continental seas—warm, shallow, and full of life—have often graced a far more equable earth with no icecaps at all, minimal climatic zonation, and habitable environments virtually to the poles. We live on a particularly harsh earth, ripe for glaciation, and our view of the past is compromised by our failure to recognize the uncharacteristic state of our present.

Forgive some geological skepticism about certain arguments often raised in our quite appropriate current concern about global warming. When ecoactivists argue that we must reduce CO_2 emissions lest the planet virtually boil away into a lifeless caldron, geologists can only laugh. The maximal greenhouse effect of any current projection would yield an earth far colder than many happy and prosperous times of our geological past. The appropriate reason for our current concern must reside in immediate effects that might be disastrous for us and our children (massive shifts in agricultural belts, drowning of cities by rising sea levels as icecaps melt), not in consequences on geological scales.

I have so far presented only an abstract defense for my key claim that our current earth remains in an ice age. Let me end then by describing an empirical argument, of a subtle and fascinating sort, developed by my colleague Steven M. Stanley, a fellow paleontologist at Case Western Reserve University in Cleveland. Stanley addresses the important subject of "lag times" with data on extinctions engendered by the harshest climates of glacial maximums.

We should not be surprised that times of continental ice sheets have provoked enhanced extinction in temperate and tropical species. But how can such data be relevant to a claim that we are still in an ice age during subsequent interglacial stages? Doesn't the return of more favorable climates engender a recovery in decimated faunas? And don't such replenished faunas wipe out the influence of glacial hard times? This argument would be incontrovertible if complex biological systems worked like Newtonian mechanics on a pool table—with immediate responses by impacted objects (balls on the table, species on the globe) to provoking causes (pool cues on the table, changing climates on the earth). But we live in a world of extended consequences and persisting signatures. Faunas don't replenish themselves with a snap of Mother Nature's fingers as soon as the good times start to roll again. Speciation is a leisurely process relative to the frequency of glacial cycles. The factory of replenishment does start to operate during interglacial periods, but the earth provides far too little

time for restocking before the next glacial epoch hits and freezes the motors. Thus, faunas can remain in their depleted glacial state throughout a subsequent interglacial time. In this important sense, we are still in an ice age because our earth maintains the signature of glacial biology even when ameliorated climates erase the physical evidence from our immediate perception.

The best-known example points to the impoverishment of our large mammal fauna in North America compared with regions of similar climate elsewhere. We shouldn't sneeze at moose and grizzly bears, but we don't have much to show for the extent of our territory. This limitation is not an intrinsic state, but the result of a recent extinction, proceeding in a sharp pulse that peaked only 11,000 years ago. A total of thirty-nine genera disappeared, including mammoths and large ground sloths. But I will not focus on this event, in part because the story is familiar, but primarily because the reasons are so sharply in dispute. This issue has provoked one of the greatest academic brouhahas of our age: was this extinction induced by climatic change (at this crucial time of peak glacial melting) or by the hunting activities of the earliest humans in America (the overkill hypothesis, with its swirling metaphors and applications to our current ecological predicaments)?

Stanley, one of the world's experts on clams, looked instead at the less controversial, far more abundant, and ever so much more tractable creatures of his expertise. Here, in the calmness of public invisibility and with a plethora of data, a convincing case can be made for extinction induced by climatic deterioration in glacial times, followed by only partial replenishment in interglacial periods of insufficient length for extensive speciation.

Stanley studied the bivalve (clam) fauna of coastal plain deposits in eastern North America (Virginia to southern Florida). In this region, several factors of local geography conspired to make climatic stresses particularly severe during glacial times. Ice sheets reached their maximal extent over eastern North America and the North Atlantic. The Labrador Current greatly increased in strength and influence, pouring cold water upon a region previously bathed in warmth. Southern escape routes were largely unavailable, as the persistently hot summers of tropical regions exceeded the tolerance of most coastal plain species. Caught in this climatic vise, the bivalve fauna of the southeastern United States was decimated. Of 361 early Pliocene species, only 22 percent survive today. (By contrast, in both

western and eastern Pacific regions, where climate did not change so drastically, and where southern escape routes remained open to temperate and subtropical species, extinction did not exceed ordinary rates of attrition for the length of time involved. In the fossil faunas of Japan and the western United States, 60 to 65 percent of early Pliocene clam species are still living.)

Moreover, the eastern American extinction shows a clear pattern of differential survival, further implicating glacial climates as the cause of death. Species with broad temperature tolerance (called eurythermal in our jargon) were hardly affected, while more finicky species, with little capacity to adapt beyond a narrow range of preferred temperatures, bore almost the entire brunt of extinction. (These narrowly channeled species are called stenothermal—an easier term to remember, since most of us know that narrowing of arteries in heart disease is called stenosis.) The magnitude of this differential is striking. The early Pliocene Pinecrest fauna of Florida includes eighty-five species that are either known to be tropical in their temperature preferences or are restricted to this local region (limited geographic extent is usually a mark of stenothermal status). Of these, sixty-nine are extinct. By contrast, fifty-seven species from the Pinecrest survive today—and all show their greater range of temperature tolerance by living in both tropical and nontropical waters. Stanley rightly concludes that "a thermal factor was operating in the mass extinction."

Another well-documented pattern teaches us that eurythermal species tend to live a long time and speciate rarely, while more narrowly adapted stenothermal forms are both more prone to extinction and subject to more vigorous branching. Thus, a differential wipeout of stenothermal forms will be especially effective in closing down the motor of replenishment after mass extinction.

This difference in evolutionary potential provides the clinching detail for Stanley's interpretation. As the glaciers began to form, and increase in strength as the ice age deepened, succeeding pulses of ice played havoc with intolerant stenothermal species. Eventually, most of the stenothermal forms disappeared, leaving a fauna composed almost entirely of more slowly speciating eurythermal species. With survivorship virtually limited to these sluggishly changing forms, interglacial episodes of ameliorated climate simply haven't provided enough time for replenishment. The motor sputters and eventually chugs into operation, but another glaciation comes along before much production can occur. In fact, the stenothermal wipeouts have been so effective that the bivalve fauna was swept clean well before the last glacial advance. Collecting clams from fossil deposits of the interglacial phase just before this last advance (as I have done extensively) is an eerie experience. Almost nothing has altered. Virtually all species are still alive and unchanged today. The fossil faunas seem like a frozen memory of our present.

In the midst of life we are in death. In the midst of warmth, we live surrounded by signatures of cold imposed by our current and still vigorous ice age. I have always been amused by the best of geological bumper stickers, often seen on my colleagues' cars—Reunite Gondwanaland. A lovely comment upon both historical inevitability and the power of geological time scales. I don't want to sound like Miniver Cheevy or some other irascible old fogey engaged in a perpetual search for a nonexistent five-cent cigar, but may I suggest another bumper sticker of similar intent—Abolish the Recent! And don't forget the capital R.

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Reinventions of Human Language

Children forced to reevolve grammar thereby reveal our brain's blueprint for language

by Jared Diamond

Try to understand this advertisement for a department store, in a language related to English:

Kam insait long stua bilong mipela—stua bilong salim olgeta samting—mipela i-ken helpim yu long kisim wanem samting yu laikim bikpela na liklik long gutpela prais.

If some of the words look strangely familiar but don't quite make sense, read the ad aloud to yourself, concentrate on the sounds, and ignore the strange spelling. As the next step, here is the same ad rewritten with English spelling:

Come inside long store belong me-fellow—store belong sellim altogether something—me-fellow can helpim you long catchim what-name something you likim, big-fellow na liklik, long good-fellow price.

A few explanations should help you make sense of the remaining strangenesses. All the words in this text are derived from English, except for the word *liklik* for "little." The strange language has only two pure prepositions: *bilong,* meaning "of" or "in order to," and *long,* meaning almost any other English preposition. The English consonant *f* becomes *p,* as in *pela* for "fellow." The suffix *-pela* is added to monosyllabic adjectives (hence *bikpela* for "big") and also makes the singular pronoun "me" into the plural "we" (hence *mipela*). *Na* means "and." Thus, the ad means:

Come into our store—a store for selling everything—we can help you get whatever you want, big and small, at a good price.

The language of the ad is Neo-Melanesian, alias New Guinea pidgin English, which serves in Papua New Guinea (PNG) as the language not only of much conversation but also of many schools and newspapers, and much parliamentary discussion. It developed as a lingua franca for communication between New Guineans and English-speaking colonists, and among New Guineans themselves, since PNG boasts about 700 native languages within an area similar to California's. When I arrived in PNG and first heard Neo-Melanesian, I was scornful of it. It sounded like long-winded, grammarless baby talk. On talking English according to my own notion of baby talk, I was jolted to discover that New Guineans weren't understanding me. My assumption that Neo-Melanesian words meant the same as their English cognates led to spectacular disasters, notably when I tried to apologize to a woman in her husband's presence for accidentally jostling her, only to find that Neo-Melanesian *pushim* doesn't mean "push" but instead means "have sexual intercourse with."

Neo-Melanesian proved to be as strict as English in its grammatical rules and as capable of expressing complex ideas. Its supple vocabulary is based on a modest number of core words whose meaning varies with context and becomes extended metaphorically. As an illustration, consider the derivation of *banis bilong susu* as the Neo-Melanesian words for "bra." *Banis,* meaning "fence," comes from that English word as spoken by New Guineans who have difficulty pronouncing our consonant *f* and our double consonants like *nc.* *Susu,* taken over from Malay as the word for "milk," is extended to mean "breast" as well. That sense, in turn, provides the expressions for "nipple" (*ai* [eye] *bilong susu*), "prepubertal girl" (*i no gat susu bilong em*), "adolescent girl" (*susu i sanap* [stand up]), and "aging woman" (*susu i pundaun pinis* [fall down finish]). Combining these two roots, *banis bilong susu* denotes a bra as the fence to keep the breasts in, just as *banis pik* denotes pigpen as the fence to keep pigs in.

At first, I ignorantly assumed that Neo-Melanesian was a delightful aberration among the world's languages. It had obviously arisen in the 170 years since English ships started visiting New Guinea, but I supposed that it had somehow developed from baby talk that colonists spoke to natives they believed incapable of learning English. Only when I began working in Indonesia and learned the language did I sense that Neo-Melanesian origins exemplified a much broader phenomenon. On the surface, Indonesian is incomprehensible to an English speaker and totally unrelated to Neo-Melanesian because its vocabulary is largely Malay. Still, Indonesian reminded me of Neo-Melanesian in its word use and in the grammatical items that it possessed or lacked.

As it turns out, dozens of other languages resemble Neo-Melanesian and Indonesian in structure. Known as pidgins and creoles (I'll explain the difference later), they have arisen independently around the globe, with vocabularies variously derived largely from English, French, Dutch, Spanish, Portuguese, Malay, or Arabic. Their interest stems from the insights they may offer us into human language origins, the most challenging mystery in understanding how our species rose from animal status to become uniquely human. Linguist Derek Bickerton's articles and his stimulating recent book, *Language and Species* (University of Chicago Press, 1990), have much to say on this subject and are the basis for my discussion here.

Language is what lets us communicate with one another far more precisely than can any animals. It lets us lay joint plans, teach one another, and learn from what others experienced elsewhere or in the past. With it, we can mentally store precise representations of the world and hence encode and process information far more efficiently than can any animals. Without language we could never have

conceived and built Chartres Cathedral—or the gas chambers of Auschwitz. These are the reasons for speculating that our species' Great Leap Forward within the last hundred thousand years—that stage in human history when innovation and art at last emerged, and when modern *Homo sapiens* replaced Neanderthals in Europe—was made possible by the emergence of spoken language.

Between human language and the vocalizations of any animal lies a seemingly unbridgeable gulf. As has been clear since the time of Darwin, the mystery of human language origins is an *evolutionary* problem: how was this unbridgeable gulf nevertheless bridged? If we accept that we evolved from animals lacking human speech, then our language—along with the human pelvis, tools, and art—must have evolved and become perfected with time. There must once have been intermediate languagelike stages linking monkeys' grunts to Shakespeare's sonnets. However, the origins of language prove harder to trace than the origins of the human pelvis, tools, and art. All those latter things may persist as fossils that we can recover and date, but the spoken word vanishes in an instant.

Fortunately, two exploding bodies of knowledge are starting to build bridges across the seemingly unbridgeable gulf, starting from each of its opposite shores. Sophisticated new studies of wild animal vocalizations, especially those of our primate relatives, such as vervet monkeys, constitute the bridgehead on the gulf's animal shore (*see* "In the Minds of Monkeys," by Dorothy Cheney and Robert Seyfarth, *Natural History,* September 1990). The bridgehead on the human shore has been harder to place, since all existing human languages seem infinitely advanced over animal sounds. That's what lends such interest to Bickerton's argument that pidgins and creoles exemplify two primitive stages on the human side of the causeway.

One difference between human language and vervet vocalizations is that we possess grammar—the variations in word order, prefixes, suffixes, and changes in word roots (like they/them/their) that modulate the sense of the roots. A second difference is that vervet vocalizations, if they constitute words at all, stand only for things with referents that one can point to or act out, such as "eagle" or "watch out for eagle." While our language also has words with referents (nouns, verbs, and adjectives), up to half of the words in typical human speech are purely grammatical items, with no referents. These words include prepositions, conjunctions, articles, and auxiliary verbs (such as can, may, do, and should). It's much harder to understand how grammatical terms could evolve than it is for items with referents. Given someone who understands no English, you can point to your nose to explain the noun "nose." How, though, do you explain the meaning of by, because, the, and did to someone who knows no English? How could apes have stumbled on such grammatical terms?

Still another difference between human and vervet vocalizations is that ours possess a hierarchical structure, such that a modest number of items at each level create a larger number of items at the next level up. Our languages use many different syllables, all based on the same set of only a few dozen sounds. We assemble those syllables into thousands of words. Those words aren't merely strung together haphazardly but are organized into phrases, such as prepositional phrases. Those phrases in turn interlock to form a potentially infinite number of sentences. In contrast, vervet calls cannot be resolved into modular elements and lack even a single stage of hierarchical organization.

As children, we master all this complex structure of human language without ever learning the explicit rules that produce it. The earliest written languages of 5,000 years ago were as complex as those of today, so that human language must have achieved its modern complexity long before that. Surviving hunter-gatherers and other technologically primitive peoples speak languages as complex as the rest of us do. Little wonder that most linguists never discuss how human language might have evolved from animal precursors.

One approach to bridging this gulf is to ask whether some people, deprived of the opportunity to hear any of our fully evolved modern languages, ever spontaneously invented a primitive language. Certainly, solitary children reared in social isolation, like the famous wolf-boy of Aveyron, remain virtually speechless and don't invent or discover a language. However, a variant of the wolf-boy tragedy has occurred dozens of times in the modern world. In this variant, whole populations of children heard adults around them speaking a grossly simplified and variable form of language, somewhat similar to what children themselves usually speak around the age of two. The children proceeded unconsciously to evolve their own new language, far advanced over vervet communication but simpler than normal human languages.

These new languages were the ones commonly known as creoles. They appeared especially in plantation, fort, and

trading post situations, where populations speaking different languages came into contact and needed to communicate, but where social circumstances impeded the usual solution of each group learning the other's language. Many cases throughout the tropical Americas and Australia, and on tropical islands of the Caribbean and the Pacific and Indian oceans, involved the importing by European colonists of workers who came from afar and spoke many different tongues. Other European colonists set up forts or trading posts in already densely populated areas of China, Indonesia, or Africa.

Strong social barriers between the dominant colonists and the imported workers or local populations made the former unwilling, the latter unable, to learn the other's language. Even if those social barriers had not existed, the workers would have had few opportunities to learn the colonists' tongue, because workers so greatly outnumbered colonists. Conversely, the colonists would also have found it difficult to learn "the" workers' tongue, because so many different languages were often represented.

Out of the temporary linguistic chaos that followed the founding of plantations and forts, simplified but stabilized new languages emerged. Consider the evolution of Neo-Melanesian as an example. After English ships began to visit Melanesian islands just east of New Guinea about 1820, the English took islanders to work on the sugar plantations of Queensland and Samoa, where workers of many language groups were thrown together. From this babel somehow sprang the Neo-Melanesian language, whose vocabulary is 80 percent English, 15 percent Tolai (the Melanesian group that furnished many of the workers), and the rest Malay and other languages.

Linguists distinguish two stages in the emergence of the new languages: initially, the crude languages termed pidgins, then later, the more complex ones referred to as creoles. Pidgins arise as a second language for colonists and workers who speak differing native (first) languages and need to communicate with each other. Each group (colonists or workers) retains its native language for use within its own group; each group uses the pidgin to communicate with the other group. In addition, workers on a polyglot plantation may use pidgin to communicate with other groups of workers. Compared with vervet vocalizations, even the crudest pidgins are enormously advanced in their hierarchical organization of phonemes into syllables, syllables into words, and words into word strings. Compared with normal lan-

guages, however, pidgins are greatly impoverished in their sounds, vocabulary, and syntax. A pidgin's sounds are generally only those common to the two or more native languages thrown together. Words of early-stage pidgins consist largely of nouns, verbs, and adjectives, with few or no articles, auxiliary verbs, conjunctions, prepositions, or pronouns. As for grammar, early-stage pidgins typically consist of short strings of words with little phrase construction, no regularity in word order, no subordinate clauses, and no inflectional word endings. Along with that impoverishment, variability of speech within and between individuals is a hallmark of early-stage pidgins, which approximate an anarchic linguistic free-for-all.

Pidgins that are used only casually by adults who otherwise retain their own separate native languages persist at this rudimentary level. For example, a pidgin known as Russonorsk grew up to facilitate barter between Russian and Norwegian fishermen who encountered each other in the Arctic. That lingua franca persisted throughout the nineteenth century but never developed further, as it was used only to transact simple business during brief visits. When speaking with their compatriots, each group of fishermen spoke either Russian or Norwegian. In New Guinea, on the other hand, the pidgin gradually became more regular and complex over many generations because it was used intensively on a daily basis; nevertheless, most children of New Guinea workers continued to learn their parents' native languages as their first language until after World War II.

Pidgins evolve rapidly into creoles whenever a generation of the groups contributing to a pidgin begins to adopt the pidgin itself as its native language. That generation then finds itself using pidgin for all social purposes, not just for discussing plantation tasks or bartering. Compared with pidgins, creoles have a larger vocabulary, a much more complex grammar, and consistency within and between individuals. Creoles can express virtually any thought expressible in a normal language, whereas trying to say anything even slightly complex is a desperate struggle in pidgin. Somehow, without any equivalent of the Académie Française to lay down explicit rules, a pidgin expands and stabilizes to become a uniform and fuller language.

Creolization is a natural experiment in language evolution that has unfolded independently many times over much of the world. The laborers have ranged from Africans through Portuguese and Chinese to New Guineans; the dominant colonists, from the English to Spaniards to other Africans and Portuguese; and the century, from at least the seventeenth to the twentieth. The linguistic outcomes of all these independent natural experiments share many striking similarities, both in what they lack and in what they possess. On the negative side, creoles are simpler than normal languages in mostly lacking such seemingly standard grammatical items as conjugations of verbs for tense and person, declensions of nouns for case and number, most prepositions, and the passive voice of verbs. On the positive side, creoles are advanced over pidgins in many respects, including consistent word order, conjunctions, relative clauses, and auxiliary verbs to express verb moods and aspects and anterior tense. Most creoles agree in placing a sentence's subject, verb, and object in that particular order, and also agree in the order of auxiliaries preceding the main verb and in the meanings of those auxiliaries alone and in combination.

The factors responsible for this remarkable convergence are still controversial among linguists. It's as if you drew a dozen cards fifty times from well-shuffled decks and almost always ended up with no hearts or diamonds, but with one queen, a jack, and two aces. Derek Bickerton derived his interpretation from his studies of creolization in Hawaii, where sugar planters imported workers from China, the Philippines, Japan, Korea, Portugal, and Puerto Rico in the late nineteenth century. Out of that linguistic chaos, and following Hawaii's annexation by the United States in 1898, a pidgin based on English developed into a full-fledged creole. The immigrant workers themselves retained their original native language. They also learned pidgin that they heard, but they did not improve on it, despite its gross deficiencies as a medium of communication. That, however, posed a big problem for the immigrants' Hawaii-born children. Even if the kids were lucky enough to hear a normal language at home because both mother and father were from the same ethnic group, that normal language was useless for communicating with kids and adults from other ethnic groups. Many children were less fortunate and heard nothing but pidgin at home, when mother and father came from different ethnic groups. Nor did the children have adequate opportunities to learn English because of the social barriers isolating them and their worker parents from the English-speaking plantation owners. Presented with an inconsistent and impoverished model of human language in the form of pidgin, Hawaiian laborers' children spontaneously "expanded" pidgin

into a consistent and complex creole within a generation.

In the mid-1970s, Bickerton was still able to trace the history of this creolization by interviewing working-class people born in Hawaii between 1900 and 1920. Like all of us, those children soaked up language skills in their early years but then became fixed in their ways, so that in their old age their speech continued to reflect the language spoken around them in their youth. (My children, too, will soon be wondering why their father persists in saying "icebox" rather than "refrigerator," decades after the iceboxes of my parents' own childhood disappeared.) Hence, the old adults of various ages, whom Bickerton interviewed in the 1970s, gave him virtually frozen snapshots of various stages in Hawaii's pidgin-to-creole transition, depending on the subjects' birth year. In that way, Bickerton was able to conclude that creolization had begun by 1900, was complete by 1920, and was accomplished by children in the process of their acquiring the ability to speak.

In effect, the Hawaiian children lived out a modified version of the wolf-boy story. Unlike the wolf-boy, the Hawaiian children did hear adults speaking and were able to learn words. Unlike most children, however, the Hawaiian children heard little grammatical speech, and much of what they did hear was inconsistent and rudimentary. Instead, they created their own grammar. That they did indeed create it, rather than somehow borrowing grammar from the language of Chinese laborers or English plantation owners, is clear from the many features of Hawaiian creole that differ from English or from the workers' languages. The same is true for Neo-Melanesian: its vocabulary is largely English, but its grammar has many features that English lacks.

I don't want to exaggerate the grammatical similarities among creoles by implying that they're all essentially the same. Creoles do vary depending on the social history surrounding creolization. But many similarities remain, particularly among those creoles quickly arising from early-stage pidgins. How did each creole's children come so quickly to agree on a grammar, and why did the children of different creoles tend to reinvent the same grammatical features again and again?

It wasn't because they did it in the easiest or sole way possible to devise a language. For instance, creoles use prepositions (short words preceding nouns), as do English and some other languages, but there are other languages that dispense with prepositions in favor of postpositions following nouns, or else noun case endings.

Again, creoles happen to resemble English in placing subject, verb, and object in that order, but borrowing from English can't be the explanation, because creoles derived from languages with a different word order still use the subject-verb-object order.

These similarities among creoles seem instead likely to stem from a genetic blueprint that the human brain possesses for learning language during childhood. Such a blueprint has been widely assumed ever since the linguist Noam Chomsky argued that in the absence of any hard-wired instructions, the structure of human language is far too complex for a child to learn within just a few years. For example, at age two my twin sons were just beginning to use single words. As I write this paragraph a bare twenty months later, still several months short of their fourth birthday, they have already mastered most rules of basic English grammar that people who immigrate to English-speaking countries as adults often fail to master after decades. Even before the age of two, my children could make sense of the initially incomprehensible babble of adult sound coming at them, recognize groupings of syllables into words, and realize which groupings constituted underlying words despite variations of pronunciation within and between adult speakers.

Such difficulties convinced Chomsky that children learning their first language would face an impossible task unless much of language's structure were already preprogrammed into them. Hence, Chomsky reasoned that we are born with a "universal grammar" already wired into our brains to give us a spectrum of grammatical models encompassing the range of grammars in actual languages. This prewired universal grammar would be like a set of switches, each with various alternative positions. The switch positions would then become fixed to match the grammar of the local language that the growing child hears.

However, Bickerton goes further than Chomsky and concludes that we are preprogrammed not just to a universal grammar with adjustable switches but to a particular set of switch settings: the settings that surface again and again in creole grammars. The preprogrammed settings can be overridden if they conflict with what a child hears in its local language. But when a child hears no local switch settings because it grows up amid the structureless anarchy of a pidgin language, the creole settings can persist.

If Bickerton is correct and we really are preprogrammed at birth with creole settings that can be overridden by later experience, then one would expect children to learn creolelike features of their local language earlier and more easily than features conflicting with creole grammar. This reasoning might explain English-speaking children's notorious difficulty in learning how to express negatives: they insist on creolelike double negatives, such as "Nobody don't have this." The same reasoning could explain the difficulties that English-speaking children have with word order in questions.

To pursue the latter example, English happens to be among the languages that use the creole word order of subject, verb, and object for statements: for instance, "I want juice." Many languages, including creoles, preserve this word order in questions, which are merely distinguished by altered tone of voice ("You want juice?"). However, the English language does not treat questions in this way. Instead, our questions deviate from creole word order by inverting the subject and verb ("Where are you?" not "Where you are?") or by placing the subject between an auxiliary verb (such as "do") and the main verb ("Do you want juice?"). My wife and I have been barraging my sons from early infancy onward with grammatically correct English questions, as well as statements. My sons quickly picked up the correct order for statements, but both of them still use the incorrect creolelike order for questions, despite the hundreds of correct counterexamples that my wife and I model for them every day. Today's samples from Max and Joshua include, "Where it is?" "What that letter is?" "What the handle can do?" and "What you did with it?" It's as if they're not ready to accept the evidence of their ears, because they're still convinced that their preprogrammed creolelike rules are correct.

Now let's use these studies to assemble a coherent, if speculative, picture of how our ancestors progressed from grunts to Shakespeare's sonnets. A well-studied early stage is represented by vervet monkeys, with at least ten different calls that are used for communication and have external referents. The single words of young toddlers, like "juice" as uttered by my son Max, constitute a next stage beyond animal grunts. But Max made a decisive advance on vervets by assembling his "juice" word from the smaller units of vowels and consonants, thereby scaling the lowest level of modular linguistic organization. A few dozen such phonetic units can be reshuffled to produce a very large number of words, such as the 142,000 words in my English desk dictionary. That principle of modular organization lets us recognize far more distinctions than vervets can. For example, they name only six types of animals, whereas we name nearly two million.

A further step toward Shakespeare is exemplified by two-year-old children, who in all human societies proceed spontaneously from a one-word to a two-word stage and then to a multiword one. But those multiword utterances are still mere word strings with little grammar, and their words are still nouns, verbs, and adjectives with concrete referents. As Bickerton points out, those word strings are like the pidgins that human adults spontaneously reinvent when necessary. They also resemble the strings of symbols produced by captive apes whom we have instructed in the use of those symbols.

From pidgins to creoles, or from the word strings of two-year-olds to the complete sentences of four-year-olds, is another giant step. In that step were added words lacking external referents and serving purely grammatical functions; elements of grammar such as word order, prefixes and suffixes, and word root variation; and more levels of hierarchical organization to produce phrases and sentences. Perhaps that step is what triggered the Great Leap Forward in human innovation and art within the last hundred thousand years. Nevertheless, creole languages reinvented in modern times still give us clues to how these advances arose, through the creoles' circumlocutions to express prepositions and other grammatical elements.

If you compare a Shakespearean sonnet with the Neo-Melanesian ad that introduced this piece, you might conclude that a huge gap still remains. But I'd argue that with an ad like "Kam insait long stua bilong mipela," we have come 99.9 percent of the way from vervet calls to Shakespeare. Creoles already constitute expressive complex languages. For example, Indonesian, which arose as a creole to become the language of conversation and government for the world's fifth most populous country, is also a vehicle for serious literature.

Thus, animal communication and human language once seemed to be separated by an unbridgeable gulf. Now, we have identified not only parts of bridges starting from both shores but also islands and bridge segments spaced across the gulf. We are beginning to understand in broad outline how the unique and important attribute that distinguishes us from animals arose from animal precursors.

Jared Diamond studies New Guinea birds and teaches physiology at UCLA Medical School.

Its webbed feet attest to its aquatic habits, but a platypus, like all mammals, must still come up for air.
D. Parer and E. Parer-Cook; AUSCAPE International

Tuned-in, Turned-on Platypus

As it turns over rocks on Australian stream bottoms, the animal gets all charged up about food

by Ed Gregory

In the gathering dusk, a platypus prepares to leave its cool, dry burrow in the riverbank and spend the hours of darkness in the river. It has been raining, and the river is high and flowing fast. On a dark night like this, visibility in the now muddy water must be almost nil, but this apparently does not concern the platypus, for it always keeps its eyes—as well as its ears and nostrils—shut underwater, even when the water is crystal clear. The animal slips into the water.

The platypus is after food. Its quarry includes worms, insect larvae, small crustaceans, and immature mollusks, with the occasional addition of an unwary fish or frog. Freshwater shrimps are considered a particular delicacy. To find food, which it seeks exclusively underwater, the platypus nuzzles around with its ducklike bill on the river bottom, shoveling aside stones to search for anything edible that might be hiding underneath. The bill, although tough enough to serve as a digging tool, is soft and fleshy to the touch, and its leathery skin is crammed with thousands of sensory nerve endings.

For a long time, these nerve endings were presumed to be mostly tactile in function, and the platypus was thought to find all its food entirely by touch. More than sixty years ago, however, one noted authority on the platypus, Harry Burrell, doubted that it could satisfy its food requirements (up to half its weight each day) with an essentially hit-or-miss method, even given the help of such an exquisitely sensitive tactile organ as its bill. Burrell felt sure that something else, some extra sense, was needed. "My opinion," he wrote in 1927, "is that this animal must have developed some extraordinary means of finding its prey, apart from the sense of touch, and that the sensory apparatus through which this acts is connected in some way with the fleshy nature of the bill." We are just beginning to understand how right Burrell was.

When it was first described at the end of the eighteenth century, the platypus amazed and puzzled the scientific world with its combination of a ducklike bill, soft furry body, warmbloodedness, and egg-laying method of reproduction (*see* "To Be a Platypus," by Stephen Jay Gould, August 1985). Many thought the first platypus skins brought to Europe were hoaxes, and for a time there was debate about whether the animal was really a mammal. But mammal it is (one of the world's three species of monotremes, or egg-laying mammals), and it has now surprised the world again. The platypus does have a sixth sense: it can detect weak electric fields. Moreover, it is the first mammal known to have this ability.

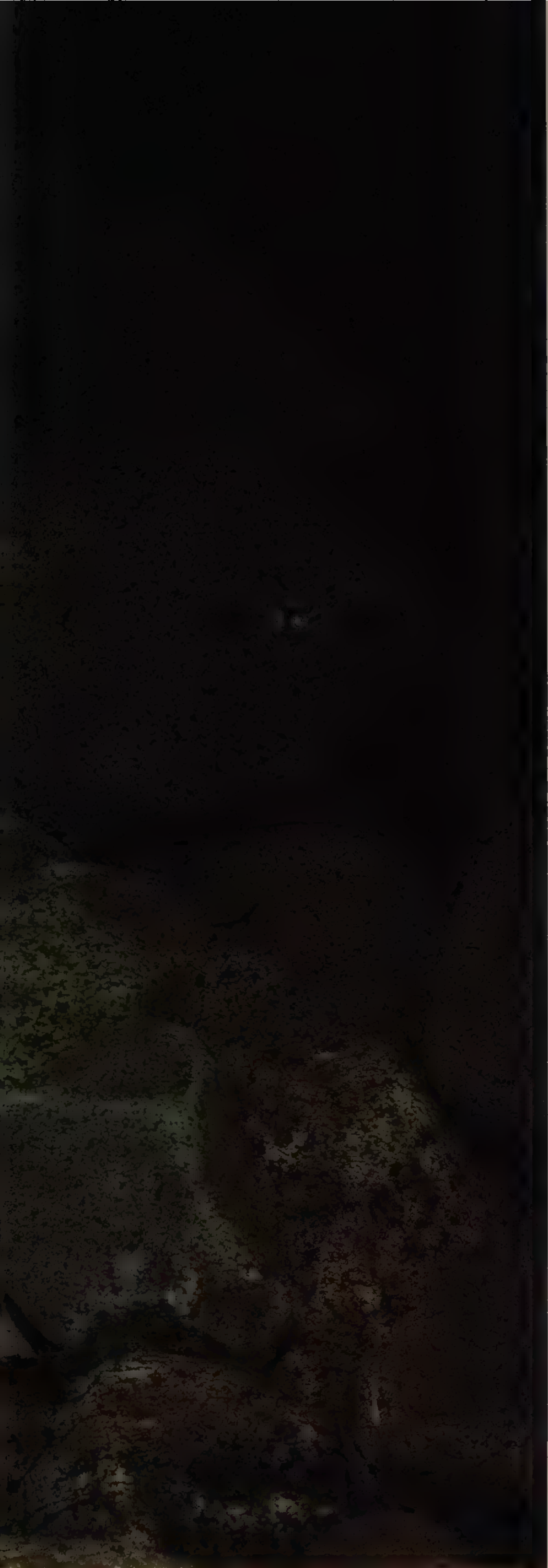
In the natural world, electric fields (areas of electric force present in the space around an electric charge) are generated in a number of ways. Thunderstorms, for example, charge the atmosphere with strong electric fields. Weaker ones are induced in currents of water as they pass through the earth's own magnetic field. As a river flows over its bed, a weak electric field forms where water and riverbed meet. Even local variations in the chemical composition of the water can generate an electric field. Animals also generate electricity: when a muscle contracts, an

oscillating electric field is set up around it. Being able to sense such fields in living things could help animals find food for themselves and avoid becoming food for others.

To take advantage of electric fields, animals need electroreceptors, specialized sensory cells or nerve endings sensitive to stimulation by weak electric fields. While air does not transmit electricity well, water does, which is why using a hair dryer or touching a radio dial while in the bathtub is such a bad idea, and indeed, nearly all the animals known to have an electric sense make their homes in wet environments. (Fortunately for them, the electric fields they are faced with in nature are much less powerful than those generated by man-made appliances.) No reptile or bird capable of detecting electric fields has yet been found, but many fishes and amphibians are equipped with electroreceptors. Some fishes have taken matters a step further, developing their own electric organs capable of generating electric discharges strong enough to stun prey and discourage predators. In all these fishes, both those able to generate electric charges and those able only to receive them, the electrosensory system has developed from the lateral line, a row of sense organs found along the side of a fish's body and typically used to detect pressure waves in the water. These electrosensitive receptors are modified hair cells, more familiar to us as the auditory receptors in our own ears.

The news that platypuses have an electric sense came in 1986 from a group of German and Australian researchers working in Canberra, who were observing the behavior of captive animals. These researchers found that hungry platypuses investigated live batteries placed in their pool, both when they were in plain sight and when they were hidden behind a brick; the animals ignored dead batteries. The platypuses also learned to avoid a transparent obstacle in the pool when an electric field was present around it but usually bumped into it when the field was turned off.

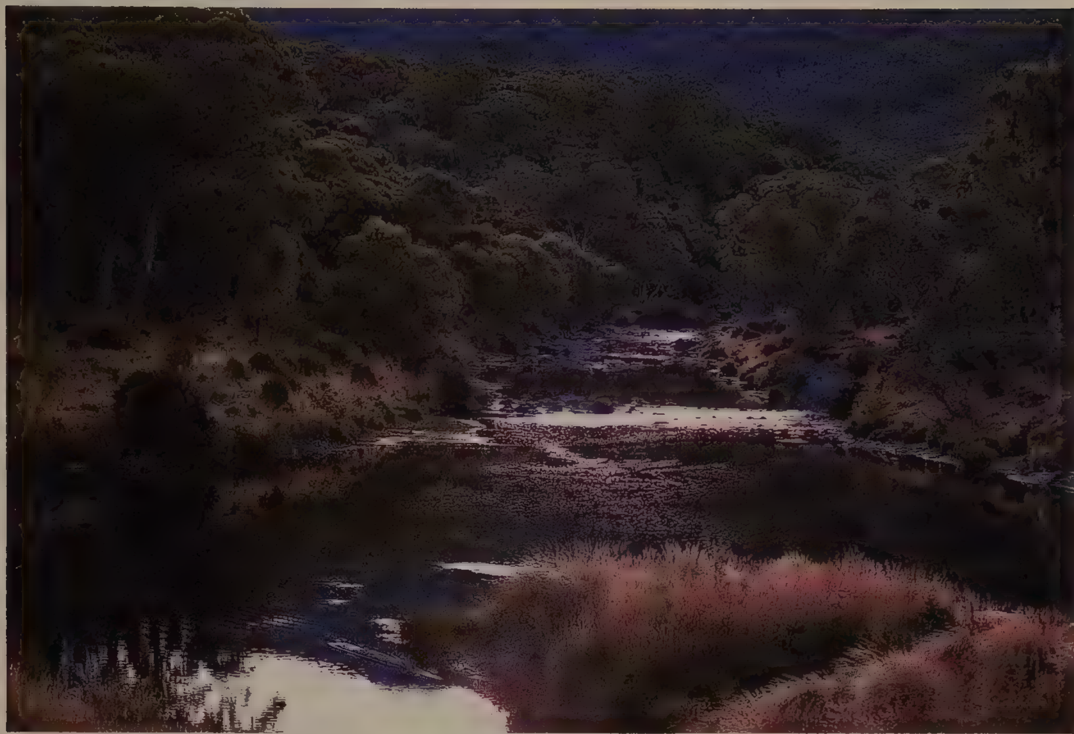
Suspecting that the platypus's electrosensitive receptors were in its bill, the Canberra researchers made recordings of brain waves while stimulating the bill electrically. The results confirmed the bill's



D. Parer and E. Parer-Cook; AUSCAPE International

Platypuses are adaptable, making their homes along both slow, muddy streams and swift, clear ones, like this river, below, in Australia's Kosciusko National Park. Left: Underwater, its eyes and ears closed, a platypus uses its bill as a shovel, leaving no stone unturned in its search for freshwater shrimps, worms, and other delicacies.

M. P. Kahl; Photo Researchers, Inc.



sensitivity to electricity. They also measured the electric field generated when a freshwater shrimp flicks its tail and estimated that the platypus's bill was sensitive enough to detect a shrimp at a distance of several centimeters.

At this point, our group, consisting of Archie McIntyre, Uwe Proske, and myself, all from Monash University, and Ainsley Iggo, a visitor from Edinburgh, entered the picture. We wanted to identify the specific receptors for the platypus's electric sense and to learn how they function. The first step was to obtain some platypuses. Although the species lives in many of eastern Australia's rivers and lakes, from the tropical north to the cold highlands of Tasmania, it is not an easy one to keep in captivity, and in spite of repeated attempts, only one animal has ever been bred in captivity. So, after obtaining a permit to study a few individuals, we set out to catch the animals ourselves. Platypuses are thought to be still common over most of their range, and we soon found a few likely places, each a small, slowly flowing, and usually muddy stream a few hours' drive from our laboratory in Melbourne. This kind of stream seems to be a favorite haunt of platypuses, although they also live in lakes and swift, clear streams. The animals are most active between dusk and dawn. To catch them, we set nets in the stream before dark and then camped on the riverbank overnight, checking the nets at intervals to see what we had caught. Often it was only fish, but sometimes we were lucky, and then we would retrieve our nets, break camp, and return to Melbourne with our prize.

From the work of nineteenth-century German anatomists, and particularly from the more recent studies of Karl Andres, also German, we already knew quite a lot about the anatomy of the platypus's bill and the detailed structure of its sensory receptors. Thick nerves, totaling nearly a million individual nerve fibers, run from the bill to the brain. These transmission lines bring information, by way of nerve impulses, from the sensory receptors in the skin. Their very large number, nearly as many as the number of optic nerve fibers entering the human eye, shows what an important sensory organ the bill must be. For comparison, a human finger tip contains about 1,000 nerve fibers; the entire skin of a hand has fewer than 20,000 fibers. The Canberra behavioral experiments had indicated that the receptors for the electric sense were in the bill. Surely, we figured, some of these many nerve fibers, previously thought to be all touch or temperature sensitive, must be connected to the electroreceptors.

A simple hand lens reveals the surface of the bill to be covered with thousands of small projections and pores. The projections are the tips of pushrods, structures unique to monotremes and consisting of a column of cells extending through, and attached loosely to, the surrounding epidermis. Sensory nerve fibers run the length of the pushrod; at its base are two kinds of organs found in other mammals as well and known to be sensitive to touch. Interesting, but not what we were after.

The bill's pores are the openings of three kinds of glands that extend nearly a millimeter below the surface of the skin: two secrete mucus and a third produces a thin, serous secretion. One of the mucous glands had no sensory nerve fibers running

The platypus bill is covered with thousands of tiny pores and projections, below. Right: A small area of the bill is shown greatly magnified. The projections (A) are sensitive to touch. The pores lead to three kinds of subcutaneous glands. One kind (associated with pore type B) has no sensory nerve fibers. The other two (pore types C and D) are innervated, but only one (D), shown at far right opening up at the bill's surface like a rose, has proved to be electrosensitive.

Frank Groeneveld

Karl Hermann Andres

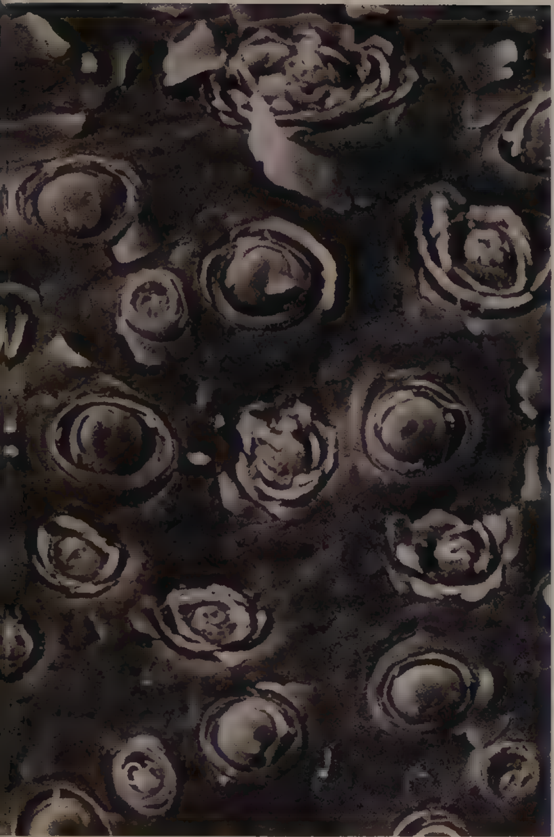
through it, so we ruled it out. But both the other type of mucous gland and the serous gland are innervated. In one of these, the mucous gland, we found some of the electroreceptors we were looking for.

In all three glands, a duct leads from the surface pore down to the part of the gland that produces the secretion. In the innervated glands, there is a swelling near the bottom of the duct; into this swelling run several of the nearly one million nerve fibers that supply the bill. These fibers penetrate the outer wall of the gland and end as fine terminals protruding inward toward the duct. Experiments that delivered weak electrical stimuli to the pores on the bill surface confirmed our suspicion that the innervated mucous glands contain electroreceptors. The actual receptors are presumably the fine terminals of the nerves running into the gland. These receptors are quite different from the electroreceptors in fish. Mucus in the duct provides a good electrical pathway to the skin surface, and a peculiar plug of cells (arranged somewhat like the petals of a rose) in the gland's pore may keep the mucus from drying out when the platypus is out of the water. The sensory mucous glands are distributed over the bill in longitudinal rows alternating with rows of the other, noninnervated mucous glands. (The innervated serous glands are scattered evenly across; we don't yet know if they, too, are electrosensitive.)

The receptors are in a constant state of activity. Even when no electric field is present, they discharge impulses continuously at a rate of twenty to fifty per second, ready to detect most any electric field a platypus might encounter in the water. Our experiments showed that the receptors reacted to electric fields with a strength of only four-thousandths of a volt per centimeter; the Canberra work had demonstrated even greater sensitivity, with the platypus responding to fields with a strength of only two ten-thousandths of a volt per centimeter or less. A comparable field strength would be produced in a river 250 feet wide if a flashlight battery were connected to electrodes at either bank.

In addition to responding to steady electric fields, the receptors could be excited by fields oscillating up to 300 times per second. They were most sensitive to fields oscillating about 100 times per second. This would be just right for finding shrimps, which generate an oscillating field at about this frequency when the tail is flicked. The movements of other prey,

Karl Hermann Andres



such as fishes, earthworms, and insect larvae, might also generate detectable electric fields.

We feel certain the platypus uses its electric sense in hunting, but many questions remain. Does the platypus merely detect the presence of an electric source and then home in on it, or can it also determine direction and distance? When underwater, the platypus moves its head and bill from side to side continuously; might this have something to do with electroreception or scanning?

While we continue to investigate the platypus's remaining secrets, we are also curious about the other monotremes: the echidnas. There are two species, both entirely terrestrial: the long-snouted New Guinea echidna and the short-snouted Australian echidna. The Australian echidna lives in habitats from arid semidesert to tropical rain forest; the New Guinea species inhabits mostly humid montane forests. Preliminary experiments that we carried out with the short-snouted echidna have led us to believe that it, too, has an electric sense. From the work of Karl Andres, we already knew that the skin of the echidna snout contains sensory structures similar to, although less elaborate than, those in the platypus. The innervated mucous glands are present in the tip of the snout, for example, but not all over it. Our own physiological experiments demonstrated that like the platypus bill, the tip of the echidna's snout is sensitive to weak electric fields. Not all the receptors are continuously active, and in the presence of electric fields, echidnas discharge nerve impulses at a lower rate than does the platypus, but the degree of sensitivity is about the same; that is, the weakest field that excites the platypus's receptors stimulates those of the echidna, as well. The echidna seems to compensate for its dry terrestrial environment by having a perpetually runny nose: the end of its snout always seems to be moist.

The news that Australian echidnas have an electric sense was greeted by some of our colleagues with a degree of skepticism. We decided to test the ability of captive animals to recognize and respond to weak electric fields.

The natural diet of echidnas is mainly ants and termites, although they occasionally eat earthworms, beetles, and moth and beetle larvae. Using powerful, clawed forelimbs, echidnas will burrow three feet into ant nests to reach the inhabitants inside, favoring especially the fat-rich virgin

Kathie Atkinson; AUSCAPE International

When its head is out of water, the platypus, below, relies on its eyes and ears. Recent evidence suggests that one of its monotreme relatives, the short-snouted Australian echidna, right, may use its electric sense on dry land, thanks to a perpetually runny nose.

D. Parer and E. Parer-Cook; AUSCAPE International

queens. The snout must also be strong to break apart pieces of rotten wood in search of food. Our two captive echidnas had an easier time of it. We fed them a mixture of scrambled eggs and lactose-free milk, which they appeared to relish, and given the chance, they would eat prodigious quantities.

Both of our animals had the endearing, rather comical rolling gait characteristic of echidnas, but their personalities were quite distinct. One was a bit of a slob, spending most of its time under a mound of wood shavings in the corner of its enclosure and emerging only at mealtimes to empty its food bowl rapidly and noisily, before retiring to the wood shavings again. The other animal was inquisitive and appeared to take an interest in the comings and goings around it. It also enjoyed its food but had better table manners.

To prepare for our experiment, we trained this second echidna to press a lever in either of two small troughs with the tip of its snout; whenever it did, a small door opened, allowing access to a supply of the scrambled food mixture. The echidna caught on quickly. We were soon able to feed it exclusively in this way, each feeding session consisting of repeated lever-pressing trials. Sometimes the echidna seemed to get bored with the game and, ignoring the levers, tried to open the food door with its snout. When this happened, we would give it free access to the food and continue the training sessions later.

Then we made the game more difficult. We filled the troughs with water and put electrodes at either side of them. This way, we could make the echidna put its snout into an electric field of known strength when it pressed a lever to open the food door. At first the echidna objected to sticking its nose in water, but it soon decided that a wet nose was better than going hungry. We started out generating electric fields in both troughs, hoping the echidna would now associate electric fields with food.

Next—for the real experiment—we put an electric field in one trough at a time and opened the food door only when the echidna pressed the lever in the trough with the field in it. The echidna met this challenge, too, and was soon pressing the right lever significantly more often than the wrong one. In one trial, it scored twenty-five correct out of twenty-five. Seemingly, this echidna could indeed sense an electric field.

Finally, to estimate the animal's sensitivity to electric fields, we gradually reduced the strength of the field in the troughs. The echidna scored well down to a field strength of two-thousandths of a volt per centimeter; below this, it pressed the wrong lever as often as the right one.

What could echidnas use an electric sense for? Given their dry surroundings and hard exoskeleton, ants and termites are not likely to produce electric fields. Echidnas also sometimes eat beetle larvae, however, and their behavior when searching for these soft, underground grubs suggests that an electric sense may come in handy then. Echidnas looking for beetle larvae stick their noses in the ground from time to time as they move around, leaving snout-shaped, conical holes. Perhaps they are feeling for electric fields set up as grubs move.

An intriguing alternative has been suggested by a colleague, David Morgan. He proposes that the modern echidna, finding itself in a drier environment than the one it evolved in millions of years ago, has adapted its electroreceptors to the new conditions and turned them into gas detectors. The receptors could now be used to locate hidden concentrations of termites, for example, not by the feeble electric fields they might generate, but by the methane they produce. According to Morgan's idea, enzymes on the wet tip of the snout would catalyze the oxidation of methane in what would be, in effect, a biological electrochemical cell. The electrical activity resulting from the operation of the cell would stimulate the electroreceptors. Methane-oxidizing enzymes are known in bacteria, so the idea seems feasible, if unconventional.

If further study proves Morgan's idea correct, then monotremes will have surprised us once again. I look forward to learning about the electrical capabilities of the long-snouted echidna. This species feeds almost entirely on earthworms, which generate electric fields as they move through the moist soil. Whether these fields are strong enough to be detected by an electric sense, or whether the New Guinea echidna even has such a sense, is not yet known. But I would like very much to take a trip to New Guinea one day to find out. □

Tiger Hunt

Rapacious predators, tiger beetles have evolved a remarkable system of camouflage to avoid becoming prey

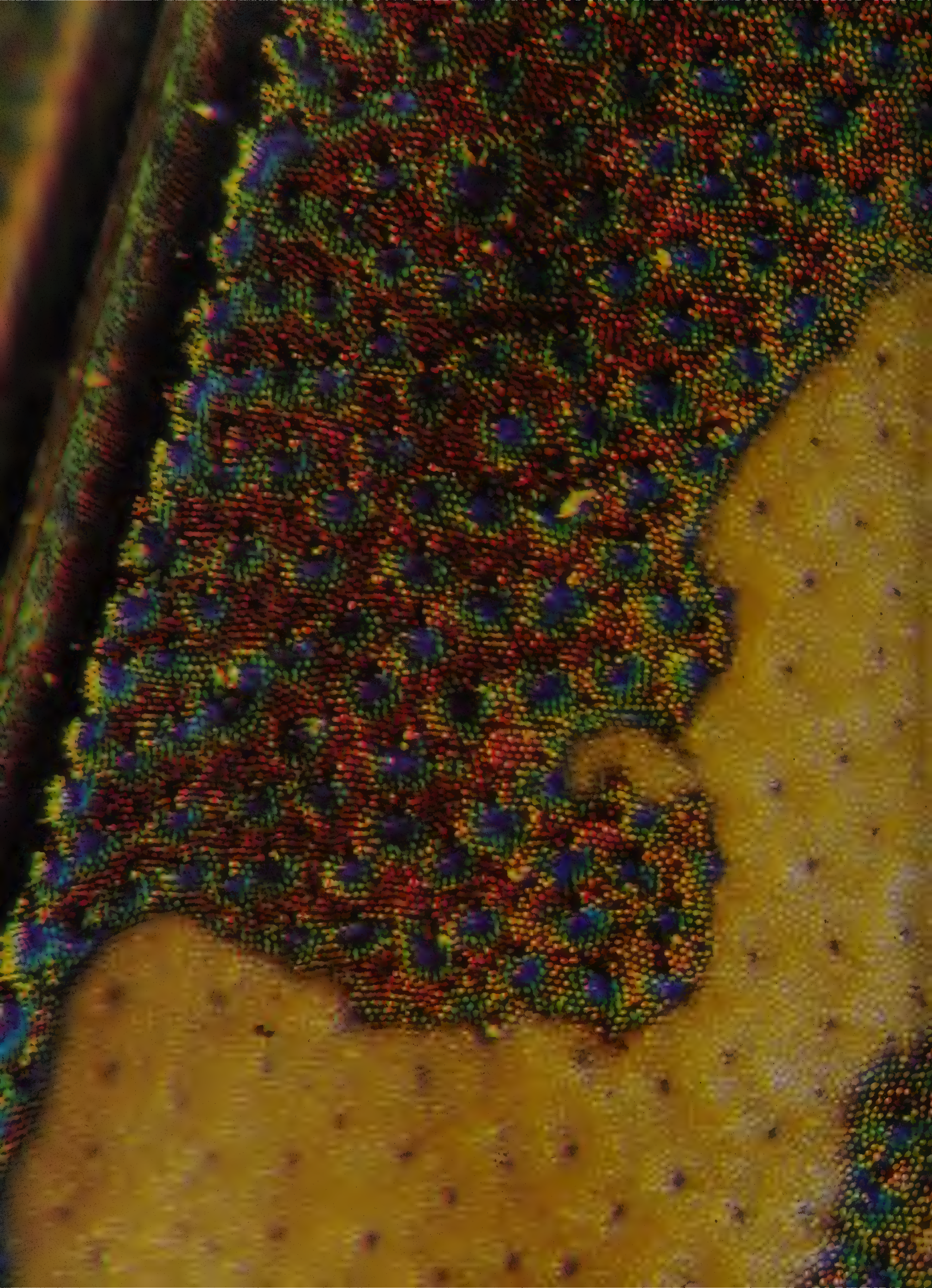
by Tom Schultz

On a sunlit stream bank in central Arizona, a tiger beetle dashes across the hot sand and with its sickle-shaped jaws seizes a small cricket. The jaws' serrated edges slash and puncture the victim, while the beetle uses its other mouthparts to devour the prey's soft tissue and juices. Resting momentarily amid the remains of the cricket, the tiger beetle cleans off its mouthparts like a warrior wiping blood from his sword. It immediately begins searching for its next meal through huge, hemispherical eyes that scan the beach horizon for any trace of movement. With its long, agile legs, it is the fastest runner among the beetles, and few insects that come within eyesight will escape.

In its larval form, a tiger beetle is no less ferocious, although its method of predation relies more on stealth than speed. The larva lies in ambush at the top of a narrow, vertical tunnel that it has dug in the soil. Its head and the forward part of its thorax rest flush with the surface, forming a trapdoor to the tunnel's entrance. When an ant or other small insect passes near it, the larva springs into action. Sharp mandibles snap upward to seize the hapless insect. The larva then drags the prey into the tunnel for consumption.

Yet even the most fearsome of nature's predators often become prey themselves, and tiger beetles are no exception. My research has focused on how adult tiger beetles manage to avoid predators. While observing the beetles in the field, I can't help but think of them in military terms. Like the light tanks used in desert warfare, tiger beetles are encased in armor (the rigid exoskeleton and two hardened forewings that shield their bulk), and yet they remain fast and maneuverable on open sand. They are remarkably adept at detecting threats from several yards away—as any entomologist, amateur or otherwise, who has tried to catch them knows. When attacked, tiger beetles employ defensive tactics, including chemical deterrents and evasive maneuvers. Once a beetle senses that an approaching object is too large to be potential prey—a whiptail lizard, for example—it sprints a few yards away. If it can't shake its pursuer, the beetle stops and turns to face its adver-

On a patch of sand near Santa Cruz, California, an Oregon tiger beetle devours a fly.
William E. Ferguson



The colors that blend together to produce brown camouflage on a tiger beetle's wing cover can be seen at high magnification. The spots and the red background are composed of tiny dimples that reflect light. The white area, one of the beetle's stripes, is covered with similar pits, but they lack melanin pigment and do not reflect color.
Ed Bridges

sary. The predator may strike, but its quarry is already gone; like a Harrier "jump jet," the beetle can take flight instantly and usually evade any enemy on land. Flying in a zigzag pattern across a stream, the beetle alights on the opposite bank and immediately resumes its relentless patrol on the new beachhead.

To carry the military analogy further, tiger beetles, like tanks or airplanes on the ground, are particularly vulnerable to attack from the air. Because they hunt during the day and because they prefer exposed ground where they can absorb sunlight to raise their body temperature enough to permit rapid locomotion and flight, tiger beetles constantly place themselves in full view of predators. (The actual time they may be seen moving, however, is minimized by short, quick dashes between long periods of sitting.) Birds frequently sight tiger beetles from a distance and attack them on the ground or in flight as they attempt to escape. On more than one occasion, I watched western kingbirds and black phoebes swoop down from their perches and snap up tiger beetles. Unable to react quickly enough, the beetles could not evade these aerial assaults. Robber flies posed another threat as they waited on nearby grass stems for insects to fly past. Intercepting the tiger beetles in midflight, the flies used their sharp beaks to pierce a beetle's soft spot, which is exposed when its wing covers are open. Often the robber flies would follow me through a meadow to snatch any tiger beetles that my footsteps disturbed and sent into flight.

Tiger beetles have evolved a variety of protective colorations to counter this situation. Where vegetation is abundant, they sport brilliant metallic colors that may confuse or deceive a predator once the attack is under way. In the eastern United States, for instance, forest tiger beetles are a stunning iridescent green and quite conspicuous in their preferred sun-dappled clearings, but the second they take flight, they disappear completely against the mottled background of their green surroundings. In arid landscapes, however, the beetles have evolved a variety of camouflage colors. Like military vehicles, they

Pointillism in Art and Nature

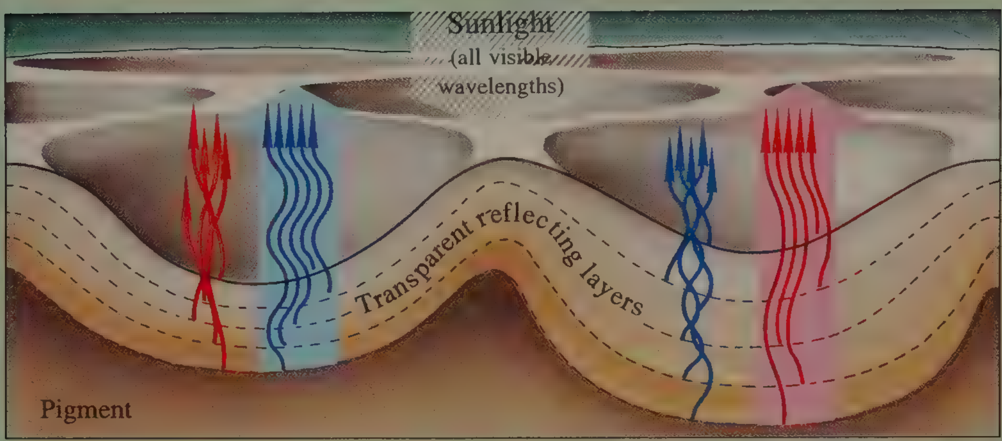
With a palette limited to brilliant metallic colors, how do some tiger beetles manage to produce the dull earth tones needed for camouflage? Recently, Gary Bernard, of Yale University, and I discovered that the beetles display the same optical illusion that was used by the pointillists, a school of neoimpressionist artists founded by Georges Seurat in the late 1800s. In perhaps the most famous example of this style, *Sunday Afternoon on the Island of La Grande Jatte,* Seurat used thousands of tiny brushstrokes of pure colors to create the colors he wanted. From a distance, the viewer's eye mixes the dots together to produce the desired hues.

The iridescent spots of the tiger beetle (so small that they cannot be distinguished by the naked eye) are similar to Seurat's brushstrokes. We perceive the camouflage colors because our eyes are "averaging" the beetle's brilliant colors. The brown forewing colors of many camouflaged tiger beetles, for example, are made up of metallic blue-green spots (each composed of about a dozen reflecting pits) surrounded by a metallic red field. The eye blends the different colors together so that we see brown. (Such blending of colors is apparent in two common technologies: blue, green, and red spots are mixed to produce all the colors on a television screen, and if you examined the photographs in this magazine under a magnifying glass, you would find that the colors are composed of only four colors—cyan, magenta, yellow, and black.) The whole range of camouflage colors displayed by tiger beetles is achieved with such mixtures. The reddish brown color of Canyon de Chelly beetles is a blend of yellow-green spots on a red field, and the black in Carrizo Creek beetles is really a mixture of magenta spots (themselves mixtures of violet and red) against a metallic green field. The dull appearance of the colors is enhanced by the unevenness of the beetles' forewings. This wafflelike surface scatters much of the reflected light, so that to the observer's eye the mixed colors appear dark and dull—similar to the colors of the natural background.

Sunday Afternoon on the Island of La Grande Jatte, *Georges Seurat (1859–1891). The task of applying countless dots of oil paint to the canvas, which measures roughly seven by ten feet, occupied the French neoimpressionist from 1884 to 1886.*
Helen Birch Bartlett Memorial Collection, 1926.224.

Against mottled sands in Death Valley, this tiger beetle is well camouflaged.
William E. Ferguson

Cross Section of a Tiger Beetle's Exoskeleton



Joe LeMonnier

The colors of a tiger beetle are produced by the surface of the insect's exoskeleton, which under extreme magnification resembles a waffle. The hundreds of thousands of tiny pits are lined with transparent reflecting layers, less than three ten-thousandths of an inch thick, which can only be seen with the aid of an electron microscope.

The thickness of the layers in any given pit determines what wavelength of light, or color, the pit will reflect. Each layer reflects all the wavelengths of the incoming sunlight, but only the light waves from a very narrow portion of the spectrum produce the colors we see. As the waves bounce off the multiple reflecting layers, only one wavelength will emerge from the pits in phase. The waves that are in phase reinforce one another; the rest emerge out of phase, canceling one another out. (This is analogous to what happens when two sets of waves traveling across the surface of the ocean meet: if the troughs and crests of one set coincide with those of the other, they enhance each other; but if the crests of one wave train coincide with the troughs of the other, the net effect is no waves at all—they cancel each other out.) Which wavelength emerges from an individual pit is determined by the thickness of its layers. In the diagram above, the thin-layered pit on the left reflects shorter wavelengths of light in phase and therefore emits blue light, while the thick-layered pit on the right reflects red light, which has a longer wavelength. All the colors of the visible spectrum can be produced by these subtle variations in the thickness of the layers.

The dimensions of the reflecting layers are determined by cells that secrete new exoskeleton when the beetle molts from a pupa into an adult. Below the reflectors, these cells also deposit the black pigment melanin, which, like the backing of a mirror, intensifies the color by absorbing any nonreflected light. The white markings on the tiger beetle forewings are areas where the reflectors and melanin are lacking.

attempt to avoid detection with color patterns that blend in with the natural background when viewed from above.

Such "cryptic" coloration is a well-known adaptation that has evolved in many animals subjected to predation. While it is not remarkable in itself, the way in which it has evolved among the tiger beetles is. The beetles achieve the dull earth tones that they need for camouflage with the same brilliant colors that are common to all tiger beetles; by blending tiny dots ranging from vivid reds and greens to iridescent blues and violets, their armor produces the most subtle hues of rock and soil with the same optical effect, known as pointillism, employed by neoimpressionist painters.

Recently, my research on tiger beetle color patterns has focused on two species, *Cicindela oregona* and *C. tranquebarica*, that are common along streams west of the Rocky Mountains. While surveying populations in Arizona and Utah, I noticed that in several locations both species shared the same stream banks. Although they vary considerably in color throughout the Southwest, the two species of tiger beetles, only distantly related, exhibited the same color patterns wherever I found them together. These color patterns matched the local background perfectly and concealed the beetles in their respective habitats.

Throughout much of the West, both beetles are usually dull brown and inconspicuous on mud or the wet sand of riverbanks. But dull, reddish populations of both species occur along a tributary of the Chinle Wash where it exits Canyon de Chelly, in northeastern Arizona. The canyon is renowned for its Anasazi ruins and beautiful pink walls of de Chelly sandstone. Weathering and erosion of these rocks leave wide point bars of fine, reddish brown sand along the banks of the Chinle Wash. The color displayed on the backs of both beetle species closely matches this background. On the Colorado Plateau, populations of either species exhibit this reddish color only where red sandstones predominate along rivers and streams.

One hundred and fifty miles to the southwest, the two species also share the banks of Carrizo Creek in central Arizona. Here the beetles' surroundings are not uniform in color as they are at Canyon de Chelly. The coarse sands lining the creek banks are either light tan when dry or dark brown where the sand is wet at the water's edge. Bluish black pebbles of basalt from nearby volcanic fields pepper the sand bars. To hide themselves amid this varied terrain, both species have evolved shades of dark purple or bluish black, although a few individuals are dark brown. At a distance of two yards or more, these beetles are indistinguishable from small basalt pebbles. The white markings on the beetles' forewings (common among most species of tiger beetles) give the color pattern an irregular shape, which helps the insects look more like a stone and less like a beetle.

Within many tiger beetle species, colors and markings vary greatly among local populations. In the populations that I studied, the variations clearly corresponded to different soil types, showing that the colors were indeed serving as vital camouflage. After the beetles originally dispersed to habitats with different backgrounds, the subsequent natural selection (by predators picking off the most conspicuous beetles generation after generation) led to the evolution of different camouflage patterns in different localities.

But how did tiger beetles evolve their remarkable ability to produce this versatile camouflage—the pointillistic blending of colors? In his essay "The Panda's Peculiar Thumb" (*Natural History,* November 1978), Stephen Jay Gould pointed out that the proof of evolution lies in those adaptations that arise from improbable foundations. The giant panda lacks a true opposable thumb. Long ago, its ancestors' five toes evolved into a bearlike paw, and only more recently, when the animals began feeding on tasty bamboo leaves, did one of their wrist bones evolve into an extra digit for grasping and stripping the stalks. The example remains a favorite for showing that the proof of evolution lies, not in optimal design, but in "odd arrangements and funny solutions . . . paths that a sensible God would never tread but that a natural process, constrained by history, follows perforce." Charles Darwin first suggested that in the evolution of any adaptation, natural selection must work on materials and structures that already exist. Because this process is not straightforward, some adaptations—the camouflage colors of tiger beetles being a prime example—may seem contrived or even paradoxical.

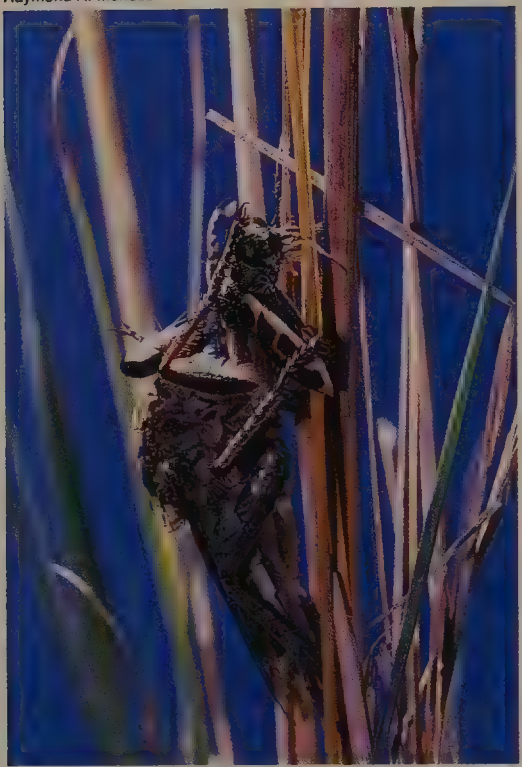
Consider the black camouflage of tiger beetles that match slate-lined stream banks or mimic black basalt pebbles. Melanin in their exoskeleton could have done the job. Indeed, some species of tiger beetles do use this pigment to appear black. But the blackness of the Carrizo Creek populations is structural, produced by the mixing of various colors from hundreds of thousands of tiny reflectors on the beetles' exoskeleton. Why mix spots of magenta with a field of green to produce the black camouflage when a simpler alternative—melanin—is possible? The Darwinian explanation is that this complex black coloration was derived from preexisting structural colors. The roundabout way in which this camouflage came about attests to the evolutionary nature of its origin.

The ultrathin layers that cause each reflector in the tiger beetle's exoskeleton to emit a specific color (see facing page) may have originally evolved to fill some other purpose (perhaps to add strength to the beetle's shell), and only with later modification did the layers produce the brilliant metallic colors. The camouflage colors came last; while iridescent structural colors are common in a variety of insects, only a very few (tiger beetles, ground beetles, and metallic wood-boring beetles) exhibit the pointillistic mixing that can produce the earth tones appropriate for camouflage. Moreover, in tiger beetles these color mosaics are confined to the upper surface; in almost all species, the lower surface, unseen by predators, retains a bright metallic appearance. Through natural selection, a surface of uniform color gradually became modified to reflect the mixed colors that produce camouflage.

Regardless of its origins, the mechanism for producing color in tiger beetles is remarkably versatile. Most animal colors are produced by various pigments, molecules that are synthesized by the animal or

Perched on a stalk of grass, a robber fly, below, consumes a tiger beetle. The fly caught the beetle in midflight and stabbed it in the back with its proboscis. The brilliant metallic sheen of a green forest tiger beetle, at right, contrasts sharply with the dull earth colors of many western species.

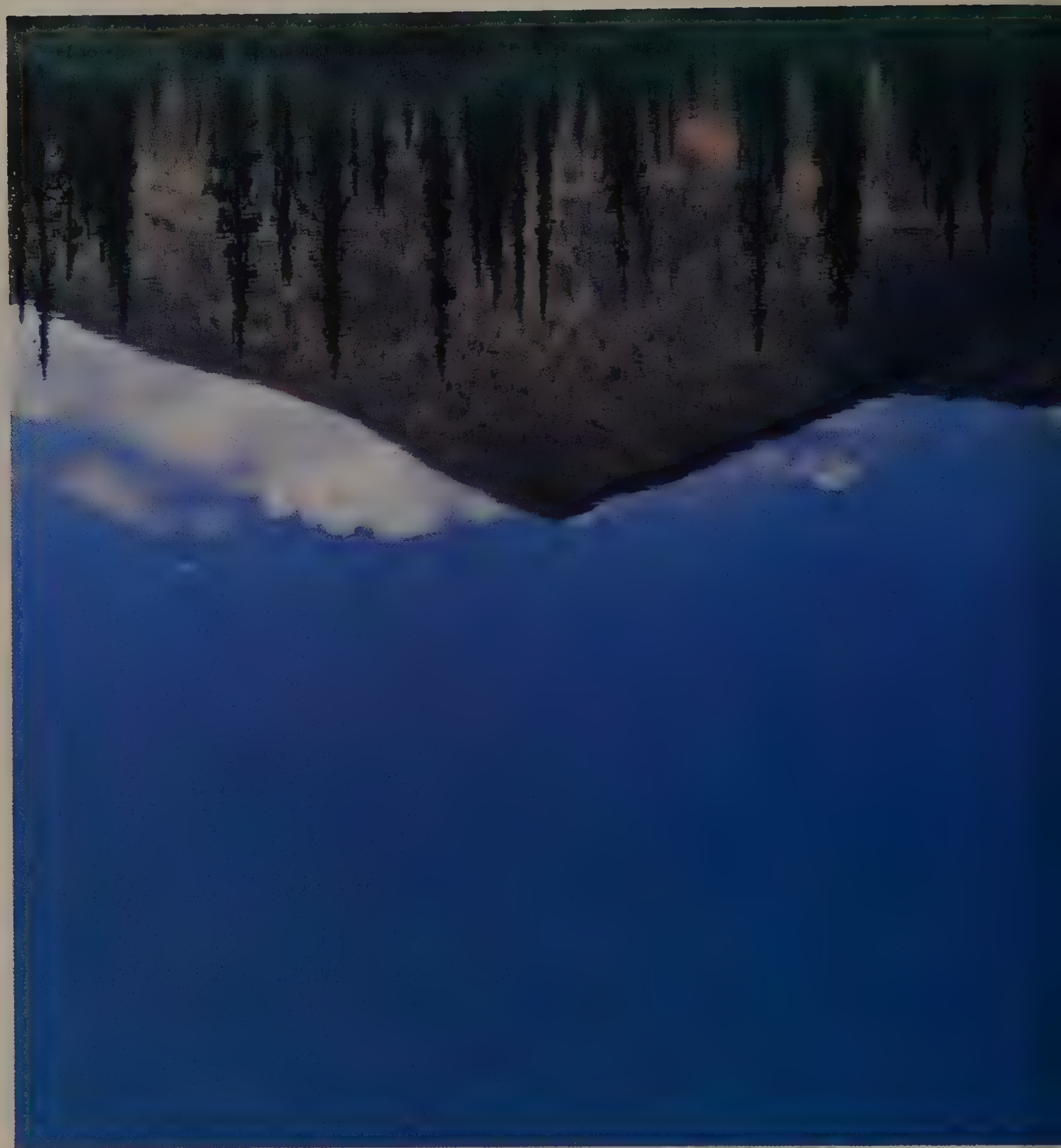
Raymond A. Mendez



acquired from the food that it eats. Generally, a species must evolve new biochemical pathways to produce new colors: green and red, for instance, are produced by entirely different pigments in nature. In contrast, small changes in the structure of the multilayer reflectors produce a wider range of colors than any one class of pigments does. In addition to producing brilliant, conspicuous colors, virtually any background hue can be matched with the appropriate combination of structural colors. The white spots or stripes contribute to the camouflage by breaking up the outline of the beetle or blending with the structural colors to produce lighter shades of background-matching colors. In some tiger beetle species, melanin deposition has been suppressed throughout most of the forewing, giving the beetles a white appearance that conceals them on bright white sand or salt flats. All these adaptive color patterns are the result of slight alterations in the genes that control melanin secretion and the thickness of the multilayer reflectors. Tiger beetles adapting to new habitats need not develop alternative pigments to blend into their surroundings; with a palette of iridescent colors and a neoimpressionist style, these insects can paint it all. □

Rod Planck/M. L. Dembinsky Jr.; Photography Associates

Happily, there is nothing at all



Up with the dawn on what appears at first as a flight of fancy. And our spirits soar.

Perhaps we should set you aright. The lakes in Canada's north, like the one pictured here, are in fact water, and not a piece of misplaced sky.

Yes, the sun does hang around for weeks on end—in high season.

No, it's not spilt red, yellow and orange paint, but rather poppies, azaleas and lichen blooms.

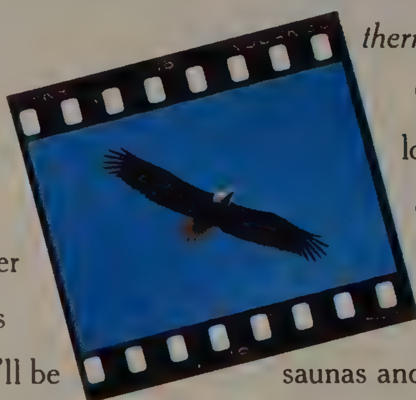
The rush of falling water, the ethereal clouds draped halfway up a granite wall, the trophy lake trout you just released—all real, all natural, all right in front of you.

Lunch, 2nd day, still touring the 'back of our guide's hand.' Some hand! But feel we're representing the 'over the hill' club commendably.

The mountains here wear the forest like a favourite old sweater—though slightly overdressed for 80° weather. All in all, comfortably sprawling.

And don't be surprised if, in this land few have seen, you bump into someone you may have lost touch with. Yourself.

It's one of those ineffable feelings you get when you happen upon a herd of reindeer as interested in you as you are in them. (You'll be pleased to note that great stretches of this land are protected by parks that also put the lifelong residents at ease.)



Pic of the day? Zoom lens on eagle circling in search of a thermal.

Of course, roadside lodges, fly-in and outpost camps go without saying. But our first-class resorts with hot tubs, saunas and second helpings may be more of your scene.

Nobody up but the moon. Sitting on the roof of the world—dazed—a million stars in front of my eyes.

For further information on travel to Canada, see page 79

A temporary kitchen and a storage area stand above the rising floodwaters of Peru's Ucayali River.
Mario Hiroka

Floodtime on the Ucayali

In the Amazon Basin, annual inundations are both a curse and a blessing

by Christine Padoch and Miguel Pinedo-Vasquez

The constant background sound of flowing water and buzzing insects was periodically broken by a gentle "plop-plop." We were spending the hot, still afternoon of March 2, 1986, sitting on the front porch of Don Rogelio Manihuari's palm-thatched farm hut, watching his newly planted cornfield disappear into the Ucayali River. With each louder "plop" another three feet and another row of his crop fell into the brown waters. Every half-hour or so Don Rogelio jumped off the porch and moved a little wooden cross, which he hoped would hold back the flood, another yard closer to his threatened house. But the cross failed to contain the waters. We finished the afternoon by helping him strip his hut of everything that could be carried off and used again, and then abandoned the structure to the Ucayali.

The flood that year on the second longest of Peru's many mighty rivers, and one of the largest rivers in all the world, was an exceptionally high one. But every year the great swirling waters of eastern Peru and other parts of the Amazon Basin rise and totally change the landscape and with it the lives of riverbank residents. The annual floods are both a blessing and a scourge to farmers of the area: the source of the riverbanks' fertility and the cause of total crop failures.

Don Rogelio did not spend the afternoon cursing the river's course; instead, he considered where he might plant the next cornfield. Although the river had stolen not only his crop but also his field, it may have granted him another, more fertile piece of land elsewhere. He would have to wait until the waters subsided, in late May or June, to figure his accounts. Until then, Don Rogelio and his fellow villagers on the Ucayali would have to use their knowledge, their wits, and a good deal of work and patience to survive on the banks of this changeable river.

Draining the eastern slope of the Andes, where in some spots rainfall is more than five times New York City's yearly average, the Ucayali annually dumps about 400 billion cubic yards of water into the Amazon just above the city of Iquitos. That discharge, however, varies greatly

The banks of an already harvested area slowly collapse into the river.
Mario Hiroka

In Iquitos, a household's medicinals and condiment herbs float on a raft for safekeeping.
Christine Padoch

with the seasons. The difference between the river's high and low levels during the year is often about thirty feet. Suspended in all that water is an enormous volume of sediment. This load of material eroded from the Andes earns for the Ucayali its designation of a "whitewater" river. Although actually closer to cocoa than to milk in color, the term differentiates the sediment-laden Ucayali from the dark, but clear and nutrient-poor "blackwaters" that also flow into the Amazon.

Many Amazonians, both past and present, have made their homes along the whitewater rivers. For when floodwaters subside each year, the silts and sands carried by those waters are left along riverbanks, on islands, and in oxbow lakes. These newly deposited soils are more fertile than most of the lands above the flood. To remain in this rich environment, Amazonians have had to learn to turn a potential catastrophe into a temporary inconvenience and ultimately into a boon.

Our afternoon's vigil on the rapidly eroding levee may suggest erroneously that Ucayalinos merely watch and wait as water takes over their land. But the days of rising waters are very busy ones. Preparations must be made both to survive the time of high water and to take advantage of the rewards a high flood brings. While we waited to learn the fate of the field and the hut, in Yahuarango, Don Rogelio's home village, manioc tubers were being processed, floors of low-lying houses were being raised, rafts were being built to serve as temporary homes for vulnerable garden plants, and pigs, chickens, cats, and dogs were being herded together to become improbable mates in miniature, dugout arks.

The farmers of Yahuarango are a particularly vulnerable group. Their settlement stands on a natural levee that floods only rarely. Their agricultural lands, however, lie mostly on low, recent deposits and are apt to be inundated or eroded in heavy annual floods. Other communities have given up the promise of higher agricultural production in exchange for the lower risk of floodless farming. These have placed their houses, as well as most or all of their agricultural enterprises, on higher ground that never floods. But such choices are not always permanent. Households and even whole villages of 100 to 200 people change location frequently.

A half-hour's walk away from the ill-fated cornfield, Doña Cecilia Panduro, Rogelio's wife, was busy pulling up the long, irregularly shaped tubers of manioc, a staple of the Ucayali diet. This particular crop of manioc had not yet reached its maximum size. The rapidly rising waters were, however, now sure to reach the field within a day or two. While most varieties of manioc will keep almost indefinitely in well-drained soils, even minimal flooding will cause the tubers to rot rapidly. Harvesting all the roots that had formed even a small starchy tuber, Doña Cecilia would preserve what she could until the flood was past. With no refrigeration available, harvested manioc becomes inedible in two days. But floodplain Amazonians have developed an ingenious technique for preserving at least part of their food supply when faced with a long and devastating flood. By peeling, soaking, and mashing the harvested manioc tubers, they reduce the roots to a starchy mass. This they bury underground, tightly wrapped in multiple layers of *bijao* leaves, on the soon-to-be-flooded levees. Several months later, when the floodwaters have subsided, the mashed manioc the farmers uncover makes an acceptable *fariña,* a coarse meal much favored in some parts of the basin.

Those farmers who invested more in plantains, the other favored staple on the Ucayali, are largely out of luck. The fruits cannot be harvested or preserved until they are at least near ripe, and much is usually lost in a high flood. Some farmers devote a portion of their fields to the few varieties of plantain that are somewhat resistant to flooding. But these, like the hardy *sapucho,* are considered to be poor in quality and not worth the trouble.

Another rescue mission carried out throughout Ucayali villages was the preservation of the multiple condiments, medicinals, and utilitarian and magical plants that typically make up a kitchen garden. The residents of Yahuarango, like most of the people of the great Amazonian floodplains in Peru, call themselves *ribereños,* riverbank dwellers of mixed European and Amazonian heritage. Although rarely acknowledging the heritage passed from tribal forebears, they maintain a great store of ancestral plant knowledge and plant collections. On the eve of the deluge, in each household, every receptacle—old cans, the shells of land tortoises long ago eaten, broken clay vessels, and half-rotten carrying baskets—is used as a container for threatened plants. The herbs are then placed on rafts or high platforms out of reach of the rising waters.

The fruit trees that all Ucayalinos tend, whether in house gardens or in extensive, mixed orchards away from the village, face varying fates. Among the hardy survivors are a few imports, like the breadfruit, that have become important in the feeding of flooded villages. Others, like the *aguaje, ungurahui,* and *huasai* palms, are native floodplain species that flourish with their feet in the water. Still other fruit trees that the Yahuaranguinos had planted were sure to fare poorly. Tempting fate, some had planted fast-growing, desirable species, such as papaya, *uvilla,* and *taperiba,* on the levees. Their fruits would fetch great prices if no high flood came, but they would not survive any inundation. All floodplain farmers take risks and count on losing a few trees and a few days of labor to the river. The future management of those fruit gardens, which we had been studying for two years, would include the replanting of some trees and perhaps some changes in design to include a less risky collection of species—if indeed this year's flood left many trees dead.

As we left Yahuarango, bound downriver to the market city of Iquitos, riverbanks recently three, six, even fifteen feet above water were now flooded. In low-lying rice lands all along the riverbank, we

After the waters have receded, a woman digs up mashed manioc tubers, wrapped tightly in leaves, that had been buried to preserve them from the flood.
Christine Padoch

saw men and women clearing land about to disappear beneath the brown waters. Some labored in water to their knees, even their waists, clearing herbaceous growth in what at first appeared to be a strangely timed operation. Apparently, all hands that could be spared from the tasks of securing present resources were out preparing for the day the flood would leave. A field, even cursorily cleared now, might well emerge after the flood a completely clear, weed-free surface, perfect for planting rice, plantains, or beans.

While the availability of market foodstuffs and of temporary wage labor make cities a magnet for those dislocated by very high floods, Amazonian cities do not escape the effect of the flood either. In the Iquitos riverbank slum of Belén, a rise in floodwaters is expected every year, and thus most houses are built on rafts or on high pilings. Some wealthier residents build sturdy, two-story houses and just expect to abandon the ground floor for a few months each year.

As it gradually became clear that 1986 would rank as a record flood year, second-floor dwellers abandoned even their topmost perches, Iquitos's great market in Belén squeezed into evermore cramped

Women process manioc tubers hastily harvested before the rising water reached them. They must be peeled, soaked, and mashed before being buried in the ground.
Mario Hiroka

quarters as all low-lying areas became swamped, and dugout river taxis did an unprecedented business. Waterborne diseases increased, and at first, rapidly harvested agricultural products flooded the market; later, papaya disappeared and the price of plantains went up sixfold.

As the flood rose to its maximum and the period of inundation lengthened, we returned to Yahuarango to see how our friends had fared. The muddy banks of the river had all disappeared, their locations merely suggested by the upper trunks and branches of trees now deep in the water. Our boat, powered by a forty-horsepower outboard motor, usually had little difficulty negotiating the upriver trip. The driver now carefully avoided the central torrent, hugging banks and islands. The greatest danger lay in suddenly losing power, because of a sheared pin or whatever, just where a strong current rushed through the trees. Many an underpowered boat had been smashed in this way, its cargo and often its passengers lost.

The river was littered with entire trees that had not held up to the flood when banks caved in, with large logs lost from timber rafts, and with many uprooted banana stalks testifying to the losses suffered by Ucayali farmers. The land, vegetation, and agriculture of the Amazon were being radically rearranged.

Just above the village of Santa Victoria de Atuncocha we came upon an arresting scene. Balanced in a minuscule dugout and leaning over a small raft tethered to an *inga* tree, a woman was apparently beating something with a canoe paddle. Almost capsizing in her agitation, the woman turned toward the sound of our motor and waved us in. We cut our motor as we approached the raft, just in time to hear the last squawks of a chicken as it sank beneath the water. "Una tremenda boa!" the woman gasped, pointing toward the murk. We saw no snake, only the last of the feathers as the chicken disappeared.

Considering our party possible saviors, the woman urged the men to dive and rescue her chicken. Not willing to face an underwater anaconda for the sake of a chicken, everyone refused. The raft on which the hapless chicken had been resident still contained a considerable menagerie: about fifteen chickens, four very small and thin pigs, three dogs, and a black-and-white cat with two kittens. A few muscovy ducks swam five feet away. Back in the house, however, the woman, Doña Maria Tangoa, counted up her considerable losses. The anaconda, together with caimans, had already robbed her of at least ten chickens and two dogs. A few chicks, she believed, had fallen off the raft and been swallowed by the giant catfish known as *zungaros*.

Doña Maria and her five children, aged eleven to four, cheered up considerably when we presented them with a bunch of plantains cut from the stalks we were bringing to our friends in Yahuarango.

These fruits, purchased at an outrageous price in Iquitos, would be a treat for folks whose staple for more than a month now had been *fariña,* breadfruit, and for those who could afford to buy it, rice.

After several minutes, a canoe approached, and Doña Maria's husband, brother, and oldest son came in. Recounting the recent adventure with the chicken and anaconda, the woman again became agitated. Her husband calmly asked her to point out exactly where the snake had disappeared underwater. Boarding their canoe, the three men and one woman, with us tagging behind in our boat, paddled out to the raft. The two older men dived in the spot where the woman pointed and moments later, to gasps from us all, brought up a writhing mass of coils: an anaconda at least eight inches in diameter. Upon reaching the water's surface, the anaconda straightened its coils, regurgitated a feather-covered blob, now unrecognizable as a chicken, and then shot away. This prize gained from the anaconda was cause for joy; what had started out as somewhat of a tragedy had turned into a gourmet meal of plantains and chicken.

Yahuarango's soccer field was now a lake, the path to the schoolhouse was a slow-flowing river, and the "Bienvenidos a Yahuarango" sign that we had helped put up two months ago was apparently now welcoming fish. Rather than tying up the boat and hauling all our cargo up a steep embankment as we were accustomed to do, we stepped directly from the boat into Don Rogelio's house. The structure, our temporary home in Yahuarango, had tilted perceptibly downriver, as had most of the hamlet's houses. Don Rogelio had already braced the leaning timbers with a few sturdy poles. When we arrived, both he and Doña Cecilia were out gathering fruits in the flooded forest. Their daughter Cleofe was the only one home, and she was sweeping around the clutter of baskets, old tins, and agricultural tools usually stored along the far wall. Cleaning, she said, was not quite as terrible now as it had been when the village first flooded. Then it seemed that every ant, beetle, rat, and snake in the forest had tried to find refuge in their house. Life was a constant struggle against the vermin.

The adults returned just as dusk was falling. Their canoe contained several species of leguminous fruits that we had very rarely seen, as well as the more familiar *aguaje* and breadfruit. In the prow was the carcass of a *majas,* one of the large and tasty rodents of the area. In this region, where dense human populations are

Annual inundations deposit rich silts that make floodplains a fertile area for growing rice.
Mario Hiroka

Farmers clear weeds and grasses in anticipation of the day the flood will recede. The weed- and pest-free soil will be planted with rice.
Mario Hiroka

settled along a very large, productive river, fish commonly outweighs meat in the diet. In some stages of a large flood, fish may be more available than ever. These are the times of the great *mijanos*, multispecies migrations of fish out of the many oxbow lakes through newly opened channels and up the Ucayali itself. Meals then consist of fish and little more, and people only bother with the tastiest species. However, when river waters spread far into the forest, fish often become hard to find. Meat, on the other hand, is more available. On broad floodplains, animals become marooned on the few patches of dry ground they can reach and are easily picked off by hunters.

The availability of other forest products also changes. Many native floodplain trees—*shimbillos, parinari, charichuelos*—fruit just as the floodwaters begin to rise. This production coincides with the enhanced mobility of *ribereños* by canoe. They now can cross swamps and follow narrow, log-jammed channels that were impassable in low water. These favorable changes, combined with a heightened need for food and cash, make flood season boom time for forest fruits in the home and the market.

Other bulky forest products are also harvested at the height of the flood. Leaves of *yarina* and *shapaja* palms, two species greatly favored for thatch, can be brought in from isolated swamps that are little exploited in other seasons; palm trunks for walls and flooring can more easily be floated down to the village. The flood, by forcing Ucayalinos to rest from agricultural tasks, sets them off searching for forest products. Many men and women are busy at this time with the manufacture and repair of tools, utensils, and handicrafts for use or sale.

The enforced rest lasts only until the first patches of agricultural land appear above water, however. Villagers then rush to get a fast-growing crop into the still-moist ground to tide them over until the earliest varieties of their favored manioc are ready to harvest in about four months; plantains take a year to bear fruit. In 1986 the first crop sowed, in late May, and the first harvested, in August, was pumpkins; a few weeks later corn came in; and then at last, at the end of September, some early, watery manioc tubers were harvested in Yahuarango.

A return to the village when the waters had receded further confirmed that a high flood is a complex mix of loss and gain. Farmers were left with riverbank and levee fields that had been cleared of rats, fungi, and diseases. Most of the land had received a new layer of fertile silt, which in some areas reached two feet in depth, and a few farmers, including Don Rogelio, our host, found their mud flat rice fields nearly doubled in size. On the other hand, Don Rogelio had lost a good acre or so of his prime cornfield to erosion of the bank, his brother-in-law's productive rice flats had become a sand-covered beach good only for a meager crop of cowpeas, and most everyone in the village was still trying to find enough planting material to fully complete the sowing of plantain and manioc. Relatives and friends from upland villages that had escaped flooding were being solicited now for plantain and manioc stalks. Many of these farmers, however, poorer than the floodplain folk in normal years, now saw a chance to prosper and were demanding high prices. The many Yahuaranguinos who, even after digging up and processing buried manioc stores, ran out of staples after the flood were also at the mercy of their upland neighbors. And traveling traders and moneylenders, eager to strike deals, persuaded many to promise a future crop of corn or

Unlikely companions wait out the flood on raised platforms and rafts.
Mario Hiroka

plantains or papayas to urban buyers for an absurdly low price.

Doña Maria, who moonlights as a curer, bemoaned the loss of several of her medicinal plants to the flood. Some of her most effective species, she claims, were brought from far away and could not be easily replaced. The flood took yet a harsher toll in other villages. In Ventiocho de Julio, six children died of diarrhea in the month of May. The normally unclean water supply grew worse as waters and refuse mixed and may have been the cause of illness; the poor food supply doubtless contributed. Most Ucayalinos, however, with their resourcefulness, their knowledge, and their great good humor, survived and later even prospered.

The story of the flood of 1986 is an exceptional one because the inundation was unexpectedly high and long lasting: approximately six feet higher and two weeks longer than the average along the lower Ucayali. More destructive yet are floods that come very early, wiping out often heavily mortgaged rice crops well before they are ripe. Also dangerous are floods with numerous *repiquetes*, short-term rises in water level after floodwaters initially recede. These can easily and repeatedly wash out several acres of newly planted rice or beans.

The flood of 1986, which had followed several other high annual inundations, intensified fears raised earlier that extensive cutting of the forests cloaking the eastern slopes of the Andes had caused Amazonian floods to become higher, more abrupt, and less predictable. Although the suggestion remains plausible and must be given serious thought, the scientific data do not exist that could conclusively prove or disprove the theory. The torrents of the lower Ucayali result from the combined flows of the many variable, unmonitored streams that rise with the fall of many unmeasured rainstorms. And from 1988 through 1990, Yahuarango has seen minimal flooding. Don Rogelio is again complaining about the plagues of rats and weeds in his cornfields. He guesses that his fields can hold out another year or two without a good drenching. By then a substantial flood might be a blessing. □

In the Drake Passage near Antarctica, a giant petrel flies low over the water, seeking crab and fish larvae that live in the ocean's nutrient-rich surface layer.
Tui de Roy; Hedgehog House

Where the Sea Meets the Sky

The ocean's skin is the richest, most extensive habitat of all

by John T. Hardy

Charles Darwin was fascinated by an explorer's account of an American black bear "swimming for hours with widely open mouth, thus catching, like a whale," thousands of insects, fish, and crustacean larvae that cluster near the water's surface. The bear that captured Darwin's imagination was exploiting an ecological niche that has only recently been studied: an immense, paper-thin habitat that blankets more than 71 percent of the earth.

Known as the sea surface microlayer, it is a remarkable "skin" that separates bodies of water from the surrounding atmosphere—the familiar dividing line between ocean and sky. Within this complex skin of the seas dwell thousands of species of plants, animals, and microbes, all attracted there by its special ability to nurture life.

Since 1989, I have been working with a team of marine biologists, chemists, and toxicologists at the Huxley College of Environmental Studies at Western Washington University investigating the biology and chemistry of the surface layer. On clear, relatively calm days, we have sampled waters as near as Puget Sound or as far away as the North Sea. Our collecting device is a barrel-sized, teflon-coated rotating drum towed alongside our research boat. Organic film from the water's surface layer adheres to this revolving cylinder and is continuously scraped by a squeegee into a large glass jar. Several quarts of the surface layer habitat can be collected by this method in just a few minutes. We also skim the surface with a special plankton net attached to pontoons, to collect samples of surface-dwelling crustaceans, fish eggs, and larvae.

Scientists have known for years that the thin aquatic surface layer teems with life. In 1917, a Swedish researcher of freshwater habitats, Ernst Naumann, coined the term *neuston* to describe certain protozoans that use the surface film for support. His coinage was taken from the Greek *neustos,* which means "floating" but refers to many inhabitants of the upper few inches of oceans and lakes. Since Naumann's time, biologists have discovered scores of plants and animals, ranging from tiny bacteria and algae to large jellyfish and seaweeds, that live, reproduce, or feed within a few inches of the surface.

Bacteria adhere to the underside of the surface film, as do some unicellular protozoans that attach themselves with a special appendage. Fish eggs are packed with fat globules, which cause them to float in contact with the surface. Other organisms, such as snails and some jellyfish and seaweeds, entrap air bubbles and float on the film. Sargassum seaweed clusters in floating mats that nurture many small creatures, including baby sea turtles.

Along with the protozoans, a dense blanket of microalgae lives at the surface layer, attracted by both sunlight and the concentration of nutrients found there. Some microalgae actually migrate to the surface at midday and then descend many feet during the night.

Capitalizing on this concentration of biota, many seabirds make their living by skimming food from the water's surface (some are even called skimmers). One of the surface layer's main attractions for shearwaters, auklets, and petrels is that it provides an important nursery ground for numerous fish species: cod, sole, flounder, hake, menhaden, anchovy, mullet, flying fish, greenling, saury, rockfish, and halibut. The tremendous risk for so many fish larvae and eggs being so near the surface appears to be balanced by the abundance of food found there and perhaps the lack of predators that live in deeper waters.

The northeast Pacific, the U. S. continental shelf, and the North Sea are typical of rich fishery areas where dozens of fish species produce eggs or larvae that concentrate at the sea surface. In Puget Sound, English sole and sand sole spawn between January and April, releasing billions of eggs that float at the surface until they hatch, generally about a week after fertilization. Because of the buoyancy of their large yolk sacs, newly hatched larvae of these flatfish often float upside down near the surface.

The ocean's skin is also a vital habitat for many commercially important shellfish at certain stages of their life cycles. Crab and lobster larvae, for instance, seek the sunlight of the near-surface, where they feed on concentrations of minuscule life forms: the microalgae and protozoans. In Chesapeake Bay, 99 percent of blue crab larvae migrate to the surface layer and spend several days feeding there. After increasing in size, the larvae return to deeper waters, where they feed upon larger foods.

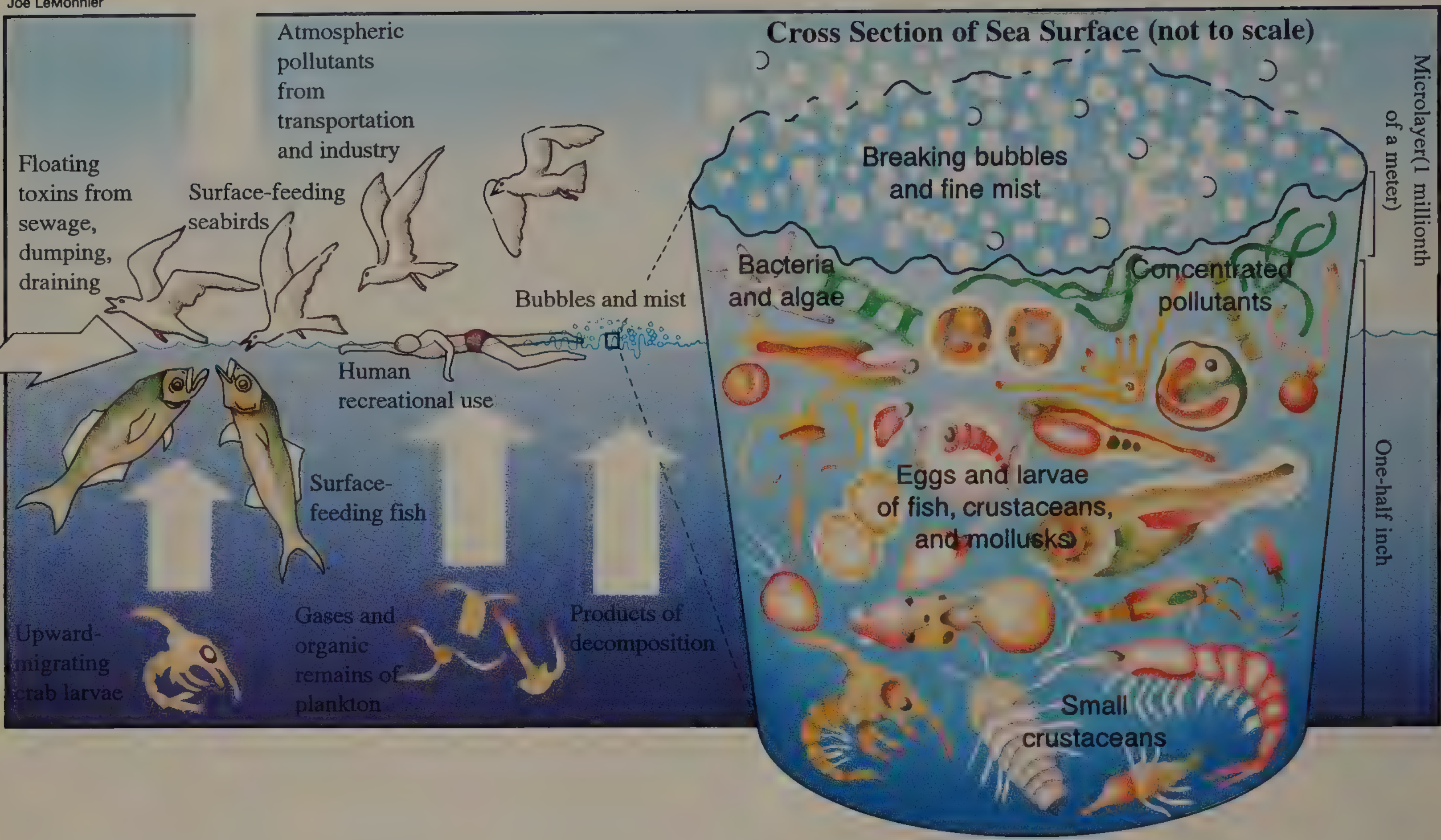
The extraordinary vitality of the sea's microlayer depends on special physical and chemical properties that are very different from those of the waters just below. The topmost three feet of water contains a whole series of sublayers, each with its own distinctive biological and chemical features. Within the surface layer (upper few feet), the first two-thousandths of an inch contains an especially dense concentration of minerals, chemicals, protozoans, and microorganisms. The upper few inches contain a greater density of larger organisms: fish eggs, fish larvae, and crustaceans. Larger, floating jellyfish and seaweeds may occupy the upper foot. The surface layer includes many transients, with plants and animals constantly migrating up and down.

The surfaces of both fresh and marine

Mark Conlin

The ocean's uppermost layer concentrates nutrients and toxins alike, below. Pollutants enter from sewage, drainage systems, or the atmosphere and are ingested by skimming birds, top-feeding fish, and sometimes, by human swimmers.
Right: A whale shark, the world's largest fish, scoops up tons of plankton from the surface layer. With gill arches modified to act as a sieve, it filters food from tropical and subtropical waters.

Joe LeMonnier



waters contain complex mixtures of chemicals that are often absent or greatly diluted at lower levels. Yet most of these natural compounds are derived from deeper-dwelling organisms. The billions of tiny plants and animals known as plankton occupy the sunlit photic zone, which may extend downward as far as 400 feet in the open ocean. The plankton excrete many organic compounds, such as amino acids, proteins, and fatty acids, that serve as nutrients for bacterial growth. Rising air bubbles capture these rich materials and carry them to the surface, where they become concentrated. When plankton die and disintegrate, some debris sinks to the bottom, but tons of cellular particles, along with oils, fats, and proteins, float to the surface.

Accumulation of these natural organic chemicals modifies the physical and optical properties of the sea surface. Thin organic films, invisible to the naked eye, are ubiquitous in lakes, oceans, and rivers. Where currents converge, these films merge and thicken; wave action sometimes makes them visible as "surface slicks." Strong surface tension acts on the slicks, resulting in a layer of sandwiched molecules, about as thick as a human hair, that resists turbulent mixing. This unique surface layer habitat even extends into the atmosphere. Just above the surface film, millions of bursting bubbles contribute to an aerosol blanket containing dense concentrations of both natural chemicals and man-made pollutants.

Metal ions, common in seawater, bind to the organic molecules and concentrate within the surface film, creating an environment that is very different from the subsurface waters. Some metal ions, such as iron, are necessary and useful to marine life; others, from human pollution, are poisonous. Such toxins as copper, lead, zinc, and cadmium, for instance, have been found in the microlayer in concentrations of 10 to 100 or more times greater than in the water below. Pesticides have been found in concentrations up to millions of times greater than in the rest of the water.

This complex aquatic surface is surprisingly stable and can hold together despite buffeting by sixteen-knot winds and four-foot waves. According to Soviet biologist Yuri Zaitsev, fish eggs, larvae, and fry can cling tenaciously to the surface layer even in waves three to six feet high. Generally, winds strong enough to whip up whitecaps and cause surface mixing are not as widespread as often imagined, occurring on less than 5 percent of the earth's surface at any given time. Even when disturbed and mixed, visible surface slicks can re-form in less than an hour after the strong winds calm down.

Because of its unique tendency to collect and condense chemicals, this resilient surface habitat is increasingly threatened by a variety of human activities, particularly the dumping of industrial wastes and widespread atmospheric pollution. Some nonsoluble pollutants bind to buoyant particles and wind up concentrated within the surface microlayer. Contaminants that fall from a fouled atmosphere collect in the natural organic films. Like nutmeg powder sprinkled on an eggnog, such par-

ticles easily become more concentrated on the surface than in the waters below.

We are all familiar with the dramatic destructiveness of large petroleum spills, although most television images are of cuddly otters and birds suffering fouled fur and feathers. However, the less visible—but much more pervasive—chronic contamination of the microlayer may present an even greater threat to many species. Oil, spreading over the water's surface at the same time that fish are releasing their floating eggs, can devastate a population's reproductive success.

Our research team and a few others have been trying to assess this less obvious danger to animals and plants that depend on the microsurface habitat for food and reproduction. In the more than 200 microlayer samples we have collected from rivers, estuaries, bays, and oceans (including Puget Sound, Chesapeake Bay, the North Sea, and the waters off Southern California and Florida), there is a sadly consistent picture: the surface microlayer is becoming a soup of toxic metals, organic pollutants, bacteria, pesticide residues, and the byproducts of combustion-derived hydrocarbons from cars, trucks, airplanes, refuse incinerators, and power plants. Coastal sewage waste-water discharges, runoff from municipal and agricultural drainage systems, and direct industrial discharges into rivers contribute to the contamination.

We assess the effects of pollution by observing the development of healthy fish eggs placed both in containers attached to moored buoys and in lab dishes filled with samples collected from polluted microlayers. Using the known data on the healthy development of fish eggs in clean water as a baseline, we have repeatedly observed that larvae hatched in polluted microlayers either die, develop slowly, or emerge malformed. We have often seen this result in some widely scattered locations throughout the world.

The same physical stability that enables the microlayer to support so much life also fosters the persistence of pollutants in high concentrations. In the presence of sunlight, some contaminants break down into even more harmful chemicals, al-

Fish eggs of many species, top, float at the ocean's surface, buoyed by their own fat globules. Larvae of reef-dwelling fish, such as tang, center, congregate near the surface to feed on tiny plants and animals, as do juvenile swordfish, bottom.

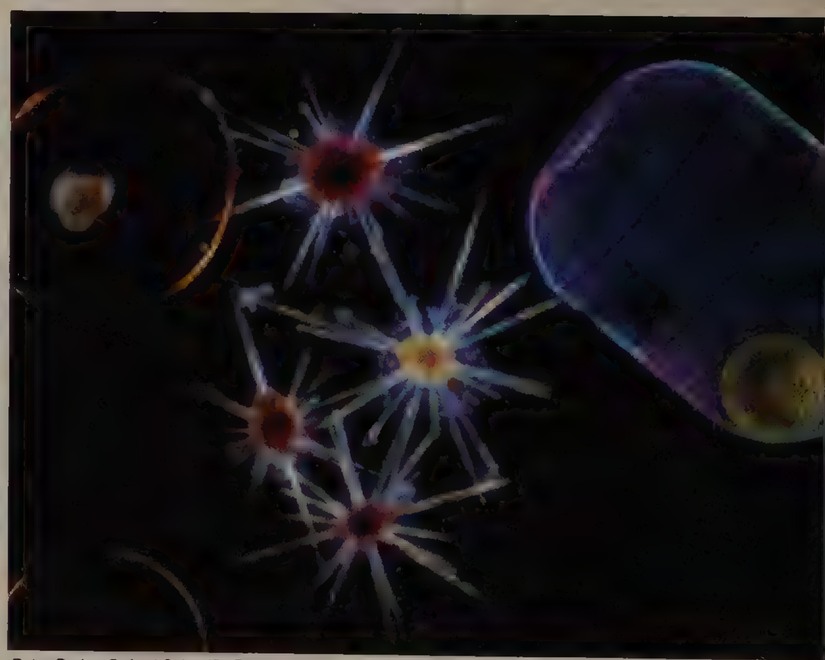
A glass jellyfish, top, moves through the upper layers of arctic waters, feeding on the various small organisms known as plankton, the same microscopic life that nourishes the great baleen whales. Bottom: A mixture of one-celled plankton, including radiolarians, diatoms, and dinoflagellates, swim in the waters off Bermuda.

Peter Parks; Oxford Scientific Films

Norbert Wu

Norbert Wu

Norbert Wu



Peter Parks; Oxford Scientific Films

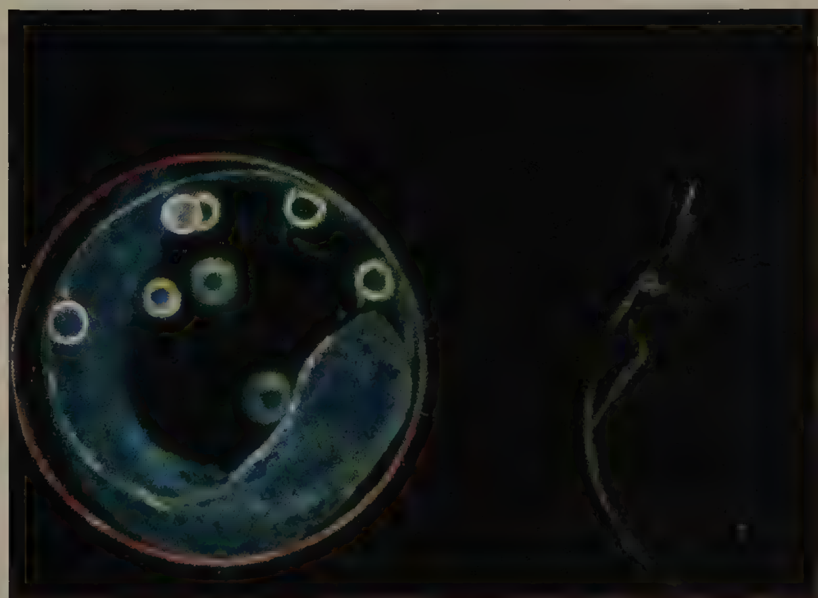
Jellyfish, which as adults feed on plankton, are themselves part of the planktonic mix when young. In extreme close-up, Porpita *jellyfish larvae, top, reveal their variable colors. Newly hatched shrimp, such as this diaphanous larva from Pacific coast waters, center, are abundant near the ocean's surface. They feed on diatoms, such as the single-celled algae, bottom, colored by light passing through their transparent bodies.*

Eerily colored comb jellies, armed with unique lasso cells that explode and ensnare their microscopic prey, top, are aggressive predators of arctic seas. The growth and development of healthy marine fish eggs, such as these from Australia's Great Barrier Reef, center, provide a good baseline for measuring the effects of toxic pollutants. Bottom: Another tiny predator of the surface layer, the copepod, is the most numerous animal not only in the plankton but also in the world.

Peter Parks; Oxford Scientific Films

Norbert Wu

David Denning; Earth Images



Peter Parks; Oxford Scientific Films

Peter Parks; Oxford Scientific Films

Peter Parks; Oxford Scientific Films

Attacked on the open seas, a Portuguese man-of-war is helpless as it floats partly submerged. The predacious snail Janthina *gets about by attaching its bubble raft to the underside of the surface film; it is impervious to the jellyfish's stinging tentacles, upon which it feeds. Minute scraps from the meal may go to the goose barnacles hitchhiking on the snail's shell.*
Kathie Atkinson; Oxford Scientific Films

though others may disintegrate and dissolve harmlessly.

Dense populations of microbiota and small animals inhabiting the aquatic surface layer form the base of an extensive food chain. While seabirds and other creatures feast on the microlayer's bounty from above, many larger organisms from the deep sea migrate upward to feed at the surface. A polluted surface microlayer has the potential to poison much of the complex marine food web, including fish, crustaceans, whales, and seabirds.

Destruction of the microlayer may even alter the exchange of materials between the atmosphere and the ocean, thereby affecting global climate. According to Robert J. Charlson, an atmospheric chemist at the University of Washington, microscopic plants (phytoplankton) from the ocean's upper layers may be part of a thermostatic system that regulates the amount of solar energy that warms the earth. A complex chain begins when the plankton produce a sulfide gas that carries particles of sulfur into the atmosphere. Cloud droplets form around them, and their density determines how much solar heat reaches the earth. According to the theories of Charlson and others, recently backed up by studies in Australia, these natural emissions are the world's main source of the nuclei for cloud condensation and a major source of sulfur. Where the layer is polluted, as in the North Sea, more sulfide gases flow into the atmosphere, producing denser clouds that cool the air. This in turn may cause a decrease in phytoplankton and a seesaw warming of the region.

Studying the sea's remarkable "skin" has confirmed our worst suspicions about the global dimensions of the poisoning of our oceans. This surface habitat is becoming as endangered as the dwindling homelands of the mountain gorilla, but its destruction may affect many more life forms. It is a vast trough for pollutants to enter into the web of life, a juncture for understanding the complexities of marine ecology, a sensitive diagnostic indicator of environmental problems, and quite possibly the key to a thermostatic system regulating global climates. □

A Passionate World of Black and White

by Wallace Stegner

Ansel Adams was all his life such a lover and defender of wilderness that both a peak and a wilderness area in the Sierra Nevada were named for him before he died in 1984. And tens of thousands of Americans, literally taught to see by Adams's great nature images, know and love those images better than they know and love the nature from which they were made.

Some, in fact, have humorously complained that no natural scene is as magnificent as an Ansel Adams photograph of it. They have a point, but the point should not be stretched to suggest that Adams has somehow deceived them or has managed to demean the nature he set out to celebrate. When he dealt with wild nature of whatever kind—mountains, forests, deserts, canyons, the sea—Adams was never anything but celebratory. His images are so impressive because he put such passion into them. He conceived the finished print to be, in Stieglitz's word, an "equivalent" of what the artist was feeling when he clicked the shutter, and he never lost his conviction that art should be an enhancement of life. What he felt in the face of grand nature was respect, wonder, awe, and that is why he could make a print of Half Dome or El Capitan, what in other hands would be a picture of a big rock, something as serene as the throne of God.


Canyon de Chelly National Monument, Arizona, 1942

Of all the stunning books that have been made from Ansel Adams's photographs, this is the most stunning. Although it does not present him at his most various, it presents him at his very best. The ninety-nine images are all of the wild nature that was his greatest enthusiasm; any one of them would qualify as an icon in the tradition of landscape photography. The range is impressive, all the way from the magnificence of Mount Denali to the feminine grace of aspen and the lacy fragility of trailside ferns. Several famous images—Yosemite Valley, El Capitan—are presented at four different seasons, in different lights. The format is large and generous, to match the subject matter, and the reproduction is impeccable. Some of the reproduction prints were made by Ansel Adams himself; those made by John Sexton at the Ansel Adams studio can hardly be distinguished, for quality, from those of the master.

Obviously the right people put this book together, completing an idea that they and

ANSEL ADAMS: THE AMERICAN WILDERNESS, edited by Andrea G. Stillman. *A Bulfinch Press Book/Little Brown and Company, $100; 146 pp., illus.*

Adams had discussed before his death. The editor, Andrea Stillman, was for several years Adams's assistant and editor. William Turnage, who wrote the introduction, was Adams's business manager before he became the energetic president of the Wilderness Society. Their familiarity with Adams's work and ideas shows not only in the selection of the images, only

Mount Clarence King, Kings Canyon National Park, California, 1925

about two dozen of which are well known, but also in the passages from Adams's books, speeches, and letters that are scattered throughout the book and that temper the grand austerity of the photographs with flashes of Adams's indignant concern for the preservation of the earth.

One quality of Adams's art, above all others, is emphasized in this book. That is the austerity, the severity almost, with which he confronts nature. In person he was one of the most gregarious and sociable of men, full of playfulness, limericks, wit, and bad puns. But when he looked through his finder at a scene that impressed him, he shrank himself down to nothing, he disappeared out of his creations. In all these ninety-nine images there is not a human figure, not even for the usual purpose of establishing the scale. Somehow the scale is here without any human figures; somehow, grandeur has squeezed the human off the edge of the print. The skies are characteristically either dark or luminous with clouds. Not a single color print is reproduced here—Adams's business led him to take many color photographs, but he much preferred black and white. His dismissive words for the color photographers were, "If you can't make it good, make it red."

In this black-and-white world of his creation the range is not of color but of light; and it is notable that even where the contrast is starkest, where black looks black and white looks white, there are always shadows of form in the whiteness and glimmers of light in the dark. Mystery is one of the things he found in nature, and he managed to photograph it. It is as if he is lurking just outside the frame, silent and reverential, contributing the power of his feeling to the picture without showing himself. Once I asked him why, since he was the last great romantic and an avowed enthusiast for nature, his pictures reminded me more of Bach than of Schubert. He said, "Because I like Bach better than Schubert." But he had to mean not the Bach of the intricate musical exercises, the partitas and fugues, but the great Bach of the Saint Mark and Saint Matthew Passions.

In life, Adams was an activist, a propagandist. In his art there is not a trace of propaganda. His photographs do not ask us to join the Sierra Club or the Wilderness Society or to follow his own example and write letters to the Secretary of the Interior. They only present, without comment, the supernal beauty of the world. And that by itself turns out to be more powerfully persuasive than any amount of urgent argument.

Opening *The American Wilderness* at any page, each one of which is a door to Ansel Adams's humbled and reverential world, I feel like taking off my hat and lowering my voice.

Wallace Stegner, who won the 1972 Pulitzer Prize for his novel Angle of Repose *and the 1977 National Book Award for* The Spectator-Bird, *was Ansel Adams's friend for more than forty years.*

Northern Cascades, Washington, 1958

A Race to Leo

by Thomas D. Nicholson

The best evening display of planets in some time takes place this spring, culminating in mid-June with Venus, Jupiter, Mars, and a crescent moon close together. Because the planets are now easy to identify in the western sky, this is a good time to become familiar with them so that you can follow them as they come together and then separate.

Finding Venus and Jupiter is easy. In the twilight glow soon after sunset, look for the two brightest starlike objects in the western sky. Venus is brighter and lower than Jupiter this month and in early June. Mars, the third player in this game of "planet catch-up," is much dimmer than at its close approach to the earth last fall, but at magnitude 1.5 it is still about as bright as Gemini's nearby Pollux and Castor, which point to it about midmonth. At that brightness, Mars is easily recognized between Venus and Jupiter by its ruddy color. Of the three planets, Jupiter is more or less stationary, drifting slowly to the left toward Leo's Regulus but remaining in Cancer until late July. Venus and Mars race to the left through Gemini and Cancer by month's end; past Jupiter and into Leo in June and July.

At the beginning of May, Jupiter is well above Venus, setting more than two hours later, and Mars is about halfway between them. By the end of the month, Venus and Jupiter are less than an hour apart, and Mars is still between them. Venus, the swiftest of the three planets, gains on Mars, while both close in on Jupiter.

In mid-May, the young crescent moon moves through Gemini and Cancer, offering an exceptional view each evening at twilight. On the 16th, the moon is below the three planets, with Venus directly above it. On the 17th, Venus is below the moon, whose upper horn points to Mars. On the 18th, Jupiter is just above the moon while Mars and Venus are well below. During all this, Gemini's bright twins, Castor and Pollux, add to the splendor of the scene.

Events in the calendar below are given in local time unless otherwise indicated.

May 1: A late-rising moon leaves evening skies dark in early May, a fine opportunity to enjoy the spring stars at their best. In the west, winter stars set early. Among them are the brilliant planets Venus and Jupiter and dimmer Mars.

May 2: The waning gibbous moon rises just before midnight in Sagittarius and moves left above the Archer's "teapot" during morning hours.

May 3: The moon is at apogee, its farthest orbital point from the earth.

May 5–6: The Eta Aquarid meteors, swift, often bright remnants of Halley's comet, peak on the 5th with about twenty per hour (less for several days before and after). Last-quarter moon interferes with viewing in the after-midnight hours. Saturn is up from about 2:00 A.M. until dawn. The moon precedes Saturn into the sky on the 5th and passes the planet before they rise on the 6th. Last-quarter moon is at 8:46 P.M., EDT, on the 6th.

May 8–12: The waning crescent moon rises later each morning among the dim stars of Aquarius and Pisces. Mercury, at greatest westerly elongation, is in best position as a morning planet on the 12th, although close to the horizon.

May 14–15: New moon is at 12:36 A.M.,

EDT, on the 14th, and perigee moon (nearest the earth) is at about 1:00 P.M., EDT, on the 15th.

May 16–17: If skies are clear, we should have a spectacular view of Venus and the crescent moon in the evening twilight both nights, with Jupiter above them.

May 18: The bright planet above the moon is Jupiter. Dimmer Mars is just below them, almost in line with Pollux and Castor (and about the same brightness), and Venus is still lower.

May 19: After passing Jupiter at 3:00 A.M., EDT, while below the horizon, the moon is above the planet tonight.

May 20: First-quarter moon, at 3:46 P.M., EDT, is just under Leo's bright Regulus after dark. Look for the "sickle" of stars outlining the Lion's head; Regulus marks the bottom of the handle.

May 22–25: The thickening gibbous moon drifts through Virgo. It is directly under the bright star Spica on the 24th.

May 28: Full moon is at 7:37 A.M., EDT. When the moon rises tonight, the reddish star next to it is Antares in Scorpius.

May 30: The moon is at apogee for the second time in May. When it rises shortly after 10:30 P.M., EDT, it's at the top of Sagittarius' "teapot" of stars. The teapot rises lying on its handle, spout upward, below the moon. Venus, in the west during early evening, is just left of Pollux.

Editor's Note: The Sky Map in the April issue shows the evening stars and constellations for this month and gives the dates and times for use.

Thomas D. Nicholson is director emeritus of the American Museum.

Otter Creek, West Virginia

by Robert H. Mohlenbrock

Originating about 3,050 feet above sea level in the Allegheny Mountains of West Virginia, Otter Creek rushes north for seven miles until, at 1,780 feet, it empties into the Dry Fork of the Cheat River. On the way it passes through a basin about four miles wide, flanked by parallel ridges that crest at 3,800 feet—Shavers Mountain on the east and McGowan Mountain on the west. The basin was extensively logged between 1890 and 1914 and sporadically beginning in 1958, but in 1972 the entire 32-square-mile drainage was set aside as Monongahela National Forest's Otter Creek Wilderness.

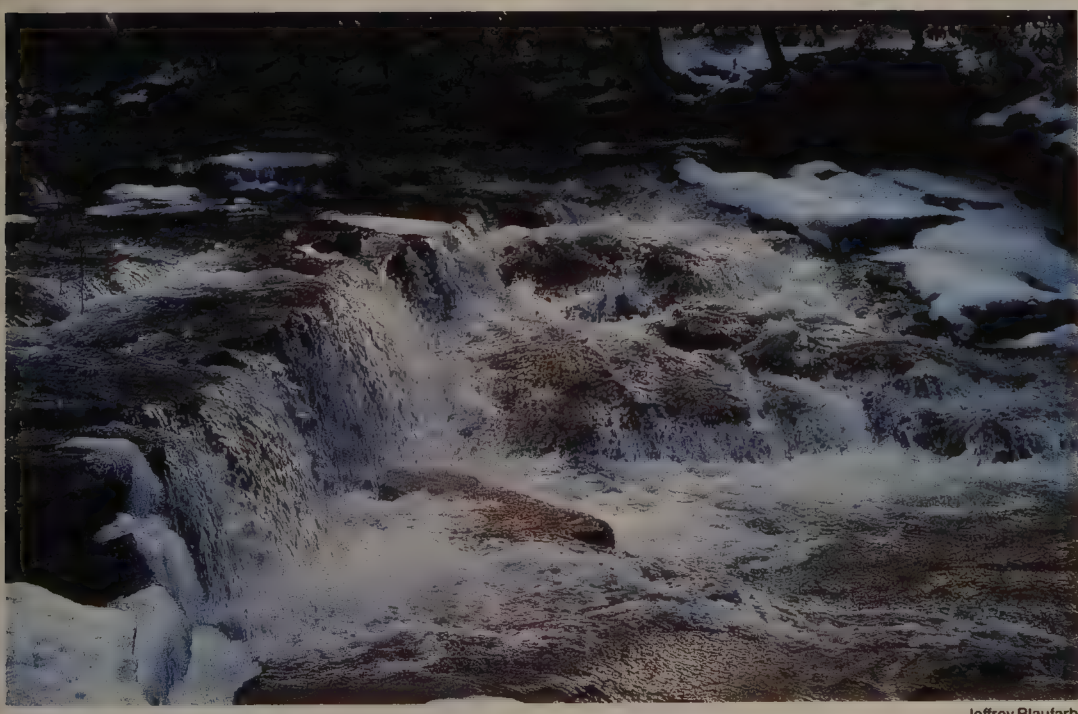
Because of the prior logging, most of the forested land is second growth, but many beautiful sugar maples, American beeches, yellow birches, and wild black cherries may be found. At higher elevations, particularly on Shaver and McGowan mountains, hemlocks and red spruces intermingle with the hardwood trees. Along Yellow Creek, one of the babbling streams that empties into Otter Creek, there is a stand of red pine. Another tributary of botanical interest is Moore's Run, whose upper reaches flow through a sphagnum bog. The bog is a legacy of the great continental ice sheet that covered the area about 12,000 years ago and scoured out depressions where water accumulates. Some of the wetland plants that have filled these depressions are the same species that grow far to the north. Sundews, gentians, yellow bartonia, white sedge, white beak rush, and skunk currant are just a few of the species recorded in the bog.

One of the animals that lives in the Otter Creek Wilderness is the West Virginia northern flying squirrel, a subspecies confined to the mountains of West Virginia and adjacent Virginia. A flying squirrel does not fly but glides, leaping as much as 150 feet from tree to tree without having to descend to the ground, where it is vulnerable to such predators as owls and hawks. The squirrel controls its glide by maneuvering the winglike flaps of skin that extend from its wrists to its ankles and using its broad, flat tail as a rudder. Wildlife photographer Tom Ulrich, who has patiently observed these secretive and nocturnal animals, notes that before taking off, the squirrel checks the distance and elevation of its target with quick head movements in a triangular motion. Once in the air, the descending squirrel rapidly gains speed, but as it approaches the landing tree, it inclines its body upward, resulting in a relatively gentle, four-point landing against the trunk.

Northern flying squirrels, which range across Canada, with extensions into the Appalachian Mountains and the Sierra Nevadas, are one of two flying squirrel species found in North America. They generally live in coniferous forests or in forests with a mixture of conifers and hardwoods, and their diet consists mostly of lichens and fungi. They are also reported to drink tree sap. The second species, the slightly smaller and lighter southern flying squirrel, lives primarily in deciduous hardwood forests from southern Maine to Florida and from the eastern Dakotas to southeastern Texas. Unlike its northern cousin, it gets most of its nutrition from seeds and nuts.

Because there are some differences among the northern flying squirrels inhabiting the various regions of North America, zoologists recognize twenty-five subspecies, including that of West Virginia. Most likely, this diversity arose as a result of the last ice age, when plant and animal species in the far north were displaced south by great glaciers. As the glaciers retreated, some species, such as the red spruce and the northern flying squirrel, were left behind on the tops of the highest mountains, which became coniferous islands surrounded by lower-elevation hardwood forests. Because of their relative isolation, the small populations of northern flying squirrels left in different regions became distinct.

The West Virginia northern flying squirrel is now so rare that it has been declared an endangered animal by the U. S. Fish and Wildlife Service and is



Jeffrey Blaufarb

Rushing north, the waters of Otter Creek, above, flow into the Cheat River. A morel, left, pokes through fallen tree leaves.

Thomas R. Fletcher

Joe LeMonnier

Jan L. Wassink

Northern flying squirrels survive on a diet of lichens, fungi, and tree sap; a subspecies inhabits the mountains of West Virginia and adjacent Virginia.

Otter Creek

For visitor information write:
Forest Supervisor
Monongahela National Forest
USDA Building, Sycamore Street
P.O. Box 1548
Elkins, West Virginia 26241
(304) 636-1800

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subject to all the protection provided by the Endangered Species Act. Wildlife biologist Craig Stihler and his West Virginia colleagues have been studying the habitat requirements and life style of the subspecies in order to prepare a management plan that will prevent its extinction. Despite intensive efforts to capture, examine, tag, and release as many animals as possible, they have located fewer than 100 specimens.

Most of the squirrels live above 3,300 feet on cool, moist, north-facing slopes in a transition zone where spruce is intermixed with several kinds of deciduous hardwoods. The squirrels require a forest zone with mature, widely spaced trees whose dense shade restricts the understory vegetation (the impenetrable tangles of rhododendron that grow beneath younger forest trees interfere with the ability of the squirrels to glide freely). The natural cavities in older, decaying hardwoods also provide the nesting sites the squirrels need, at least in the cooler seasons. Stihler has observed as many as seven adults and juveniles sharing the same nest.

One of the complications for those concerned with preserving the West Virginia northern flying squirrel is that the southern species, which inhabits hardwood forest, sometimes lives in the same area. Even though slightly smaller, the more aggressive southern flying squirrels tend to drive the northern squirrels higher up the mountain, restricting them to the limited tracts of conifer-dominated forest. In addition, researchers have found that the southern flying squirrels harbor parasitic roundworms, which are probably transmitted from animal to animal by means of an intermediate host. The southern species seems to tolerate the parasite well, but it may prove harmful if transferred to the northern flying squirrels.

"This Land" highlights the biological phenomena of the 156 U.S. national forests. Robert H. Mohlenbrock is Visiting Distinguished Professor of Plant Biology at Southern Illinois University at Carbondale.

At the American Museum

Man and Nature Lecture

Life evolved on earth for hundreds of millions of years before the Cambrian period, but until recently, fossils from this important early period were virtually unknown. William Schopf, a professor at the University of California, Los Angeles, and director of the Center for the Study of Evolution and the Origin of Life, is a pioneer in the new field of Precambrian paleobiology, a multidisciplinary approach to understanding the earliest and longest phase of life on earth. Schopf has been chosen to present the 1991 Mack Lipkin Man and Nature Lecture at the American Museum of Natural History. This public lecture series gives prominent scientists an opportunity to discuss their work and its implications for humanity. On Monday, June 10, Schopf will talk about fossil discoveries from Precambrian times and how these early organisms influenced the basic organization of the present-day biological world. On Tuesday, June 11, Schopf will discuss his conclusion that the widely accepted rules of evolution do not apply to these early organisms, which remained virtually unchanged over billions of years. Both lectures will begin at 7:00 P.M. in the Main Auditorium. Advance admission for the two-evening series costs $20 ($10 for Museum members) and may be ordered from the Membership Office, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024-5192. Call (212) 769-5606 for further information.

Asian/Pacific American Month

Crossing cultures is the theme of May's *Asian/Pacific American Month.* A ten-year exchange of letters between a California-born Chinese woman and a woman in Beijing tells of an unusual friendship that bridged the cultural and geographical gaps between them. On Sunday, May 19, the Pan Asian Repertory Theatre portrays the differences and similarities between the two ideologically opposite nations represented by these women and ends with the Tiananmen Square massacre that abruptly terminated this exchange. On Saturday, May 25, storyteller Charlie Chin brings to life the myths, legends, and folk stories of the people of China and the Chinese in America. On Saturday, May 4, an Asian American jazz group celebrates a musical synthesis of two cultures. Other programs focus on Asian and American theater in the twentieth century; oral history of Asian Americans; Asian stereotyping; the growing Filipino community in the United States; traditional Korean music and dance; Japanese American artwork from internment camps during World War II; Asians in Flushing, Queens; and a series of short films. Programs are scheduled every weekend in May except Mother's Day weekend, May 11 and 12. Call (212) 769-5315 for times, dates, and places. There is no charge, and seating is on a first-come, first-served basis.

The Great Attractor

What causes the streaming motion pulling the Milky Way and the nearest 3,000 galaxies toward the constellation of Centaurus? Alan Dressler, an astronomer with the Observatories of the Carnegie Institution, will address this question in his talk on "The Great Attractor," part of the series "Frontiers in Astronomy and Astrophysics." This lecture will be given at 7:30 P.M. on Thursday, May 2, at the Hayden Planetarium. Tickets are $4 ($3 for members). For further information, call (212) 769-5920.

Mapping the Gene

Understanding the genetic blueprint of organisms has been the lifelong work of James D. Watson. Nobel laureate, pioneer codiscoverer of the structure of DNA, Watson will talk on Thursday, May 23, at 7:30 P.M. in the Main Auditorium about the Human Genome Initiative, a fifteen-year, $3-billion program to map the genetic system and identify defective genes that cause disease. Tickets are $12 ($7 for members).

A hot-air balloon, piloted by Lorna Daily, crossed the Continental Divide in the winter of 1988. For a firsthand account of her solo flight, join Daily in the Kaufmann Theater at 7:30 P.M. on Wednesday, May 1. Admission to this program is $10 ($6 for members). On Sunday, May 5, younger members (ages five to twelve) can learn about whales. These ocean giants will be explained by Ozzie Tollefson, assisted by his participatory theater production, in the Kaufmann Theater at 11:30 A.M. and 1:30 P.M. Tickets are $8 ($5 for members).

Terrestrial giants will be the subject of a talk in the Main Auditorium by Cynthia Moss, director of the Amboseli Elephant Research Project, on Wednesday, May 15, at 7:30 P.M. Moss, who has studied more than 700 East African elephants, will describe the differences in the social lives of male and female elephants. Admission is $15 ($9 for members).

On Friday, May 17, at 7:30 P.M. in the Kaufmann Theater, musician Steve Gorn and narrator Richard Lewis will accompany storyteller Nina Jaffee in a program that highlights how chants, poems, and myths express the beginnings of language in various cultures. Tickets are $8 ($5 for members).

For the fourth year, the Spanish Dance Society returns to the Museum with a repertoire of classical, regional, and flamenco dancing on Thursday, May 30, at 7:30 P.M. in the Main Auditorium; admission is $15 ($10 for members).

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New York City's water supply system is one of the world's great engineering projects. How the system developed, its geologic features, and its future will be the subjects of slide-illustrated lectures by Sidney S. Horenstein, coordinator of the Museum's Environmental Public Programs, on May 9 and 16 at 7:00 P.M. Admission is $20 for both evenings. Starting at the Museum and ending up in Central Park, Joseph Dicostanzo, a research assistant on Great Gull Island and a past president of the Linnaean Society, will introduce beginning bird watchers to the techniques of bird identification on Saturday, May 11, 10:30 A.M. to 3:00 P.M. ($40; limited to twenty-five adults). On Sunday, May 5, from 11:00 A.M. to 6:00 P.M., a workshop by Steven Leipertz on the ancient craft of marbling will enable students to produce ten sheets of their own marbled paper using various techniques. The workshop is limited to twenty people and costs $65. Call (212) 769-5310 for more information.

These events take place at the American Museum of Natural History, located on Central Park West at 79th Street in New York City. The Kaufmann Theater and the Leonhardt People Center are located in the Charles A. Dana Education Wing. The Museum has a pay-what-you-wish admission policy. For more information about the Museum, call (212) 769-5100.

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A Portable Feast

The West Indian sandwich roti *comes directly from East Indian folkways*

by Raymond Sokolov

The flow of immigration into the New York metropolitan area is bringing the community at large into contact with people of cultures barely known before—Colombians, Ecuadoreans, Mexicans. And these are no longer splinter groups but serious, big, self-sustaining populations capable of generating enough business to support their own groceries, shops, and restaurants.

For the outsider with an interest in gastronomy this is a major boon. The restaurants of the newly arrived are aimed at that group, not at curious gourmets or even serious gastroethnographers on the prowl. This means that their clientele knows what to expect and won't be easily satisfied with food that falls short of authenticity. This is why food in Chinatown has always prospered and why one of the two highest-rated dim sum restaurants in the city is in Flushing, Long Island, the newest center of fresh Chinese settlement.

My latest brush with this phenomenon began innocently enough in my own neighborhood, within walking distance of the American Museum of Natural History. I was buying ingredients for testing some Indian recipes at a little specialty shop on Upper Broadway. It was a remarkably well supplied place, especially for the Upper West Side, which is not a center of Indian life. But why was it here? I wondered. Not just for me and other Anglo hobbyists, dabblers who weren't likely to buy basmati rice in five-kilo bags or cassettes of recorded Indian music.

Then I saw the Scotch bonnet chilies and I understood. This was a store catering to West Indians with East Indian ancestors: Trinidadians and others with a similar background who come from other islands, Jamaica, Barbados, the north of Martinique, and Guyana. Caribbeans of East Indian heritage have a culture distinct from Asian-born Indians, as any reader of V. S. Naipaul's Trinidadian fiction or his reportage from India will know. They may seem to blend invisibly into the city's larger Indian-Pakistani population, but only at the crudest level of observation. In their food, this distinctness from Indian Indians is very clear.

The New World worked its magic on the East Indians who came to the Caribbean as laborers in the nineteenth century just as it did on other new arrivals. And they too adapted their traditional foods to conditions they found in this hemisphere. The trademark dish invented by Indian immigrants to the Caribbean is a sort of curry sandwich called *roti.* You may have read about *rotis* in an exuberant piece by Daisann McLane in the *New York Times* in January.

Roti, she wrote, "is a thoroughly creole invention that has no equivalent in India." This observation succinctly raises the complex issue of what creole means. The term is meaningless if it does not refer to a New World culture that has evolved amidst a transplanted Old World population. In this sense, the Trinidadian *roti* is a perfect creolism, since it has evolved directly and obviously from Asian Indian foodways. No one familiar with Indian food would fail to note the connections or to conclude that *roti* had many sources in the cuisine of the mother country.

The word *roti* itself is the ordinary Hindi word for bread. There are a great many Indian breads made from many flours: breads that are fried, breads that are deep-fried, breads that are toasted on griddles, and breads that are baked on the walls of tandoori ovens. India has flat breads and leavened breads and puffy breads; breads that are flaky and breads that are stuffed.

Most Indian breads, however, are flat and made from a very fine whole-wheat flour called *aata,* or *chapati,* flour. Our supermarket whole-wheat flour is coarser and still has bran specks in it. Indian American cookbooks normally advise sieving U. S. whole-wheat and thinning it with white flour. In any case, the standard Indian bread one is aiming for with this flour is a flat, unleavened circular bread cooked on a griddle and called *chapati* or *roti.* The dough has nothing in it except flour and water.

The other most prevalent Indian home-baked bread is the *paratha,* also a whole-wheat, unrisen and flattish bread, but it has shortening brushed on it. Then it is folded twice and "baked" on the griddle. The interior fat layers produce a flaky effect. Plain *parathas* are triangular. Some are stuffed, with potatoes for example, and then fried on a griddle.

So in Trinidad, a pancake bread very much resembling a *chapati,* but griddle-fried like a *paràtha,* retains the standard Indian name for bread. Why is this *roti* different from the *rotis* of primeval India? Or from those rolled out by the millions in India every day of the year now?

The difference is that by textbook definitions the Trinidadian *roti* is not quite a *chapati* and not quite a *paratha.* Nor, at least in Ms. McLane's recipe (which follows what she has seen in Trinidad and Brooklyn), does this *roti* use whole-wheat flour. She calls for "flour," which presumably is white flour, and she adds a raising agent, baking powder. So the New World *roti* uses available flour and a modern chemical substitute in place of the original

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Roti

(Adapted from *Down-Island Caribbean Cookery,* by Virginie F. and George A. Elbert, Simon and Schuster, 1991)

1 cup all-purpose flour
1 cup whole-wheat flour
¼ teaspoon salt
1 teaspoon baking powder
1½ tablespoons butter cut in small pieces
6 tablespoons dhal *(see recipe below)*
Oil

1. Mix the dry ingredients together in a mixing bowl. Blend the butter into the flour mixture with your fingertips until smooth. Gradually add 1 cup warm water, stirring in with a spoon. The dough will be slightly soft. Knead it in the bowl for 5 minutes, turning, folding, and punching it.
2. Divide the dough into 6 equal parts and roll each part into balls between the palms of your hands. Set aside on a lightly floured sheet of waxed paper. Cover with a dampened piece of cheesecloth or a clean dish towel.
3. Cup a ball of dough in the palm of your hand and open the ball up around the edges, spreading it but *not thinning the center section too much.* Smooth a tablespoon of *dhal* into the opened area. Fold the edges of the dough over the purée, overlapping sections as you work around the circle, dipping a finger in water to help seal the folds. Roll the dough lightly between the palms of your hands to shape the ball.
4. Put the ball on a floured sheet of wax paper on a pastry board. With your fingers, lightly press it into a disk about 4 inches in diameter. Cover the disk with a second sheet of floured wax paper and carefully roll out a thin 9-inch disk. Roll the dough from the center without rolling over the edges. If you thin the edges too much and too quickly, the filling will spurt out. As you reach the 9-inch size, a certain amount of filling will ooze out, but just scrape it off.
5. While you are rolling out the first *roti,* heat a large, heavy frying pan or griddle on top of the stove until a few drops of water sprinkled into the pan will bounce. Brush the pan very lightly with oil and transfer the *roti* to the pan. Lightly brush the top of the *roti* with oil and turn it over. Cook on each side until browned in small blisters, smoothing the top with the back of a tablespoon.
6. Transfer the cooked *roti* to a paper towel and repeat the process of forming, rolling, and frying the dough until all the dough is used up.

Yield: Six 9-inch pancakes

Dhal
Split-pea purée

¼ cup dried yellow split peas
1 2-inch scallion top, thinly sliced
¼ teaspoon West Indian curry powder
Pepper and salt

1. Rinse peas until water is no longer cloudy. Cover with water and soak for two hours.
2. Drain and rinse peas. Pour them into a small saucepan. Add ¾ cup water, scallion slices, a pinch of curry powder, and 2 turns of freshly ground black pepper. Bring to a boil, lower heat, cover, and simmer for 40 minutes, stirring occasionally.
3. Uncover, raise heat to medium, and continue cooking for 10 minutes, stirring with a long-handled spoon (purée will spatter as it thickens).
4. Remove from heat and press through a fine sieve. Add remaining curry powder, pepper, and salt.

Roti Filling
(and final assembly)

1 cup dhal *(see recipe above)*
¾ pound trimmed, boned, and diced beef, goat, lamb, pork, or chicken or ½ pound chopped raw or cooked shelled shrimp
1 medium potato, sweet potato, or malanga, *peeled and diced*
Salt and pepper
Cayenne pepper

1. In a casserole, stir the *dhal* together with 2 cups water. Bring to a boil, reduce heat, and begin to simmer.
2. Add meat (if using shrimp, add in step 3 where noted). Stir well. Cover and simmer gently for about 2 hours, until meat is tender, adding water if mixture sticks to casserole.
3. Add water if necessary to make a slightly flowing mixture. Add salt, pepper, and cayenne to taste. Add potato (or sweet potato or *malanga*) and simmer for 15 minutes. (Add shrimp next and cook for another 3 minutes.)
4. Put a sixth of the filling in the center of each *roti.* Fold top and bottom edges of *roti* over filling so that they meet. Then fold over the sides until they meet. When this is done, the filling and the pancakes should be hot.

ingredients in the fat-flaked, folded *paratha* of Asia. It seems entirely reasonable to me to call this plate-sized, eight- to ten-inch bread a *neoparatha*. Sometimes it is made plain; sometimes it has a stuffing (as in India). But the Trinidadian *rotis* are not complete unless they have been folded around a curry filling.

I use the term *curry* advisedly. In orthodox Indian cooking, the word *curry* is a misnomer, an embarrassment we have inherited from the British raj. Real Indian cooking doesn't have curries, Indian-style dishes seasoned with a prepared curry powder. The spices vary from dish to dish. Some of these mixtures are sold commercially as one kind of *masala* or another, but not as curry. Serious cooks make their own mixtures.

But in the New World Indian diaspora, curry powders are a basic feature of life. The shop on Upper Broadway, for example, sells curry powder from the Trinidadian curry powder capital of Tunapuna. Turban brand "special Madras curry" was the creation of Hardit Singh, combining what he had learned in India and "a nuance of West Indian flavour." The mixture, which has been manufactured since 1929, contains coriander, cumin, turmeric, "mangril," fenugreek, celery, and fennel. Whatever mangril may be (dried mango?), this mixture doesn't taste much different from other, recognizably Indian flavor mixtures in Asian Indian dishes. Basically, then, the *roti* consists of a pseudo-Indian bread wrapped around a goat or chicken stew flavored with an industrial, Indian-inspired spice mixture—not so much original as something you might expect would be salvaged from tradition and altered to suit local possibilities.

The fundamental novelty of the Trinidadian *roti* is not what might be called, with misplaced severity, its ersatz elements, but its architecture. I know of nothing in Indian cooking that involves a whole disk of bread being folded like an envelope around a complete main dish. But it is easy to see how the indentured Indian laborers who arrived in Trinidad long ago took to holding their meal inside their bread, for convenience and portability. And I would not be surprised if this practice began in India among poor people making do outdoors and on the move.

In Trinidad, new ingredients were added to the fillings. The New World taro called *malanga* is one of them, an obvious analogue for potatoes, but that only brings a much older process of adaptation to New World root vegetables full circle. The potato, so popular in India, came from Peru to India sometime after the early sixteenth century, when the Spanish began sending Andean food products to Europe and Asia. Another American tuber, the sweet potato, also flourished in India and is now the basis of an Indian bread dough, for the puffy fried bread called *poori*.

There is even some question as to the inherent Indianness of Indian breads. Many of them do resemble flat breads eaten in Afghanistan, the bridge between India and the medieval Near East. Also, Indian breads are served predominantly in the north of the country; they give way to rice in the south. And it is in the north that most of the Islamic Moghul foods are typical. It is tempting to see a connection, a gastronomic cousinhood perhaps, between the flat, pocketed pita breads of the Middle East, which are so familiar to us as the pocket for a portable "sandwich" of falafel, and the folded curry sandwich of Trinidad.

Today, these movable feasts are meeting on the sidewalks of New York.

Raymond Sokolov is a writer whose special interests are the history and preparation of food.

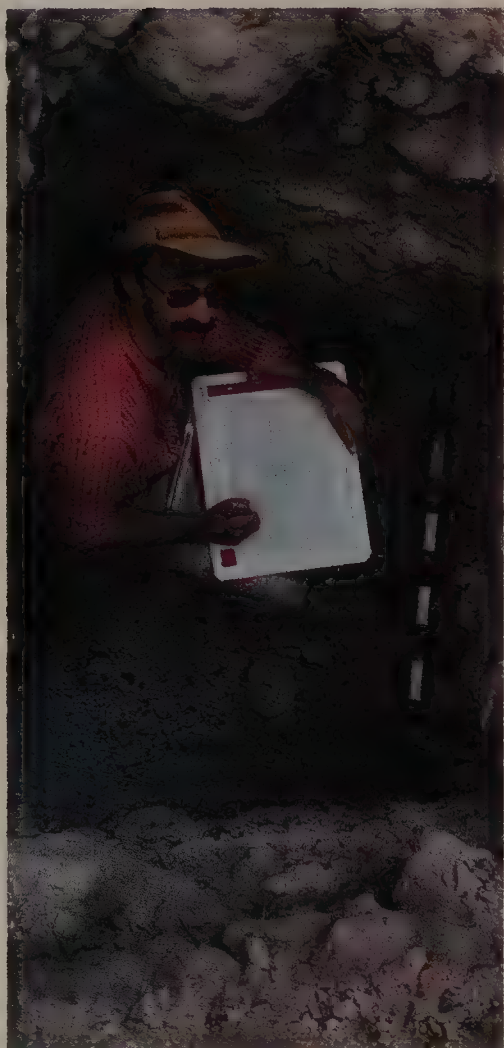
Breaking and Entering

In the Mojave Desert, a group of seven honey ants labor to remove the stamens from a cactus flower, clearing a path to the rich pool of nectar below. Each obstructing filament is snipped, carried to the edge of a petal, and discarded over the side.

These workers, in the genus *Myrmecocystus,* forage among the desert plants for nectar, which they return to their underground nests. There, the workers regurgitate the sweet liquid, transferring it to ants whose only role in life is to serve as living storage vessels. These repletes are recruited from among the largest workers soon after they emerge as adults, when their abdomens are still soft and elastic enough to expand as they are filled. The abdomen of a fully engorged replete may expand eight times in size, becoming a transparent amber globe about the size of a pea. One determined entomologist, assisted by professional gravediggers, found 1,500 repletes hanging from the ceilings of chambers in a nest that extended fifteen feet down into the Arizona desert soil. By storing nectar in relatively cool wet weather, the ants will have a reliable source of food and water to tap during the hot dry season.—*R. A.*

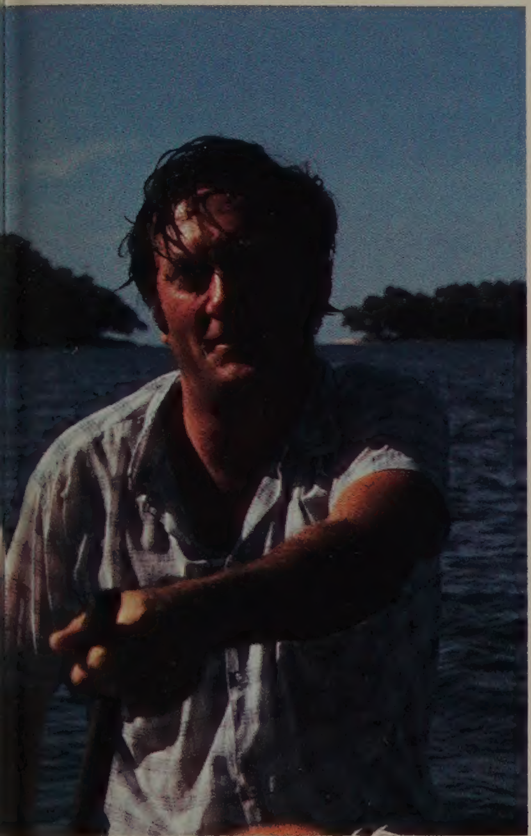
Photograph by
William E. Ferguson

AUTHORS



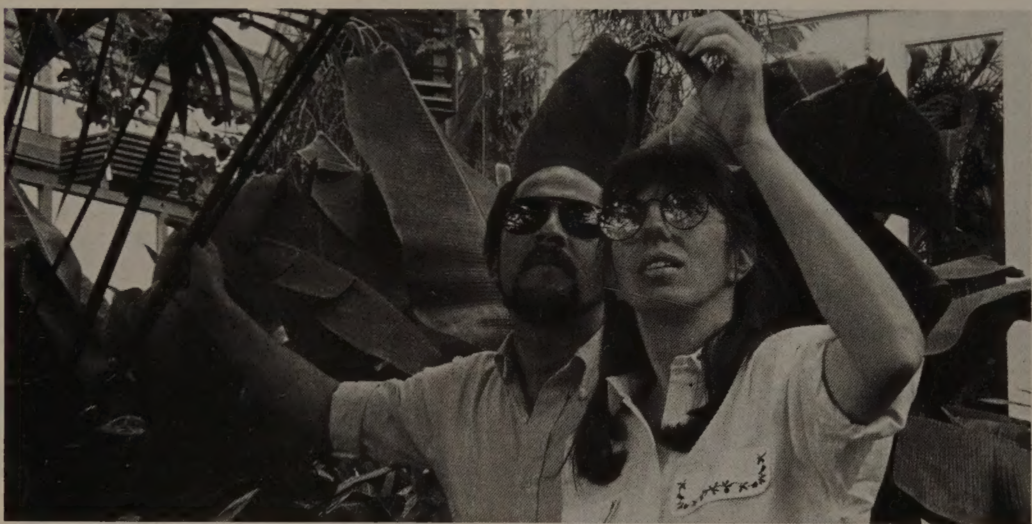
In 1979, archeologist **Richard D. Hansen** (page 8) joined others in excavating El Mirador, a site in Guatemala that has revolutionized scholars' understanding of the Maya Preclassic period. His research at the nearby center of Nakbe is adding new surprises to this chapter of Maya civilization. Hansen is a staff research associate at the Institute of Archaeology, University of California at Los Angeles, and project director of the Regional Archaeological Investigation of the North Petén, Guatemala. For a summary of findings prior to the excavation of El Mirador, he recommends reading *The Origins of Maya Civilization,* edited by Richard E. W. Adams (Albuquerque: University of New Mexico Press, 1977). For information on El Mirador, see "El Mirador: An Early Maya Metropolis Uncovered," by Ray T. Matheny (*National Geographic,* September 1987, pp.316-39).

Ed Gregory (page 30) is a research scientist in the physiology department of Australia's Monash University. His interest in unusual sensory systems dates back to his postgraduate days, also at Monash, when he studied the duck's bill for his Ph.D. Currently, his research continues to focus on electroreception in monotremes, as well as on mammalian muscle receptors and reflex functions. Since, as he says, "physiologists get little opportunity to do fieldwork," Gregory must often rely on vacations to get him out and about, paddling down the Sepik River in Papua New Guinea in a dugout canoe, for example, or taking a week-long walk in Uganda's Ruwenzori Mountains. For more on monotremes, readers can turn to Tom Grant's *The Platypus* (Sydney: New South Wales University Press, 1984) and a recent article, "The Echidna," by Peggy D. Rismiller and Roger S. Seymour, in *Scientific American* (February 1991).

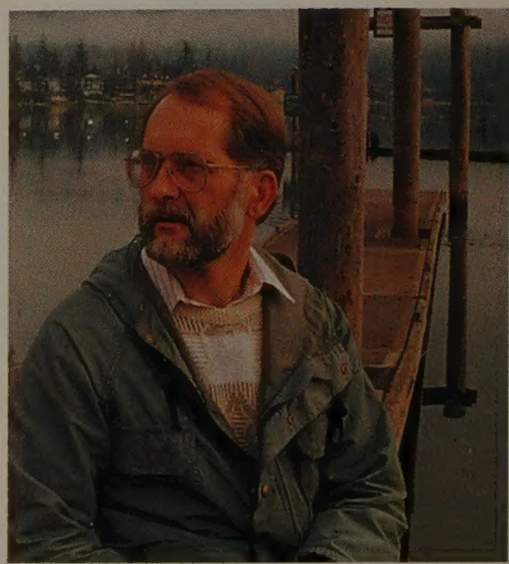


With net in hand, **Tom Schultz** (page 38) hunts for tiger beetles in the subalpine meadows of Colorado. He saw his first tiger beetle on a college field trip to Lake Michigan's dunes (where the famous ecologist Victor Shelford studied tiger beetles and their colors in the early 1900s) and became intrigued with the insects when he startled one into flight and saw a robber fly grab it. The blended colors of the tiger beetle reminded him of one of his favorite paintings at the Art Institute of Chicago, Georges Seurat's *Afternoon on the Island of La Grande Jatte.* Schultz attributes his early interest in color to his father, who worked in a paint factory. Currently, Schultz is an assistant professor of biology at Denison University in Ohio. In addition to working on the evolution of tiger beetle camouflage, he is studying camouflage colors in toad bugs and the coloration of jumping spiders. For further reading on animal camouflage, he recommends R. L. Gregory and E. H. Gombrich's *Illusion in Nature and Art* (New York: Charles Scribner's Sons, 1974).

Christine Padoch (page 48) has been part of an interdisciplinary study of native fruits of the Peruvian Amazon since 1981. "When we realized that most agricultural production came from the floodplains," says Padoch, "we turned our attention to such areas. The floods and how people adapted to them became the focus of our research." An associate scientist at the Institute of Economic Botany at the New York Botanical Garden, Padoch is now doing research on traditional forest management in West Kalimantan, Indonesia. Born and raised in a small village along the Ucayali River in Peru, coauthor **Miguel Pinedo-Vasquez** has observed floods, and how people contend with them, all his life. A student at the Yale School of Forestry, Pinedo-Vasquez is also adviser to the Small Farmer's Federation of Loreto, in Iquitos, Peru. For further information, the authors recommend Mario Hiroka's article "Mestizo Subsistence in Riparian Amazonia" (*National Geographic Research,* vol. 1, no. 2, pp. 236–46, 1985).



When in the field, **William E. Ferguson** (page 88) rarely misses the opportunity to photograph interesting insect behavior. In addition to the image of the honey ants that are the subject of this month's "Natural Moment," two of his photographs of desert-dwelling tiger beetles appear in this issue. As an entomologist, Ferguson's fieldwork has taken him to temperate and tropical areas of the world, but his focus has been insect life in North American deserts. Ferguson received his undergraduate and graduate degrees from the University of California at Berkeley. He is currently a professor emeritus of entomology at San Jose State University and is studying a group of parasitic wasps, known as velvet ants, that thrive in the deserts of the Southwest. The "Natural Moment" photograph was taken with a Nikon F camera, a 55mm Micro-Nikkor lens, and a hand-held electronic flash.



A few weeks after he read Jacques Cousteau's book *The Silent World* at the age of fourteen, **John ("Jack") T. Hardy** (page 58) donned scuba gear and began to explore the underwater world of his native southern California. From these early firsthand observations of ocean life, Hardy's boyhood interest eventually led to a doctorate in marine botany and aquatic ecology from the University of Washington. For his thesis he studied a group of tiny, obscure algae that live on the water's surface. Fascinated with this unique habitat, he has since pioneered the study of the sea's topmost layer and how it is affected by pollution. This research has led him around the world, from the Pacific islands to the Mediterranean, the North Sea, and the Atlantic Ocean. Now an associate professor at Huxley Environmental College, Western Washington University, Hardy heads a research group examining the effects of climatic change on the marine environment and continues research on the aquatic surface microlayer. He is a coauthor (with Philip W. Basson et al.) of *Biotopes of the Western Arabian Gulf* (Aramco Department of Loss Prevention and Environmental Affairs, Dhahran, 1977), the first comprehensive study of the marine ecology of the Persian Gulf. For further reading on pollution and the sea surface he recommends the special issue of the journal *Marine Environmental Research* (vol. 23, no. 4, 1987).

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